3.0 ENVIRONMENTAL BASELINE INFORMATION

3.1 INTRODUCTION

This chapter provides environmental baseline information for different regions and individual states within the U.S. that could potentially host carbon sequestration projects. The following aspects will be discussed in this chapter: atmospheric resources, geologic resources, surface water resources, biological resources, cultural resources, aesthetic and scenic resources, land use, materials and waste management, health and safety, socioeconomics and infrastructure.

3.2 ATMOSPHERIC RESOURCES

The following section describes baseline air quality with respect to the states within the Regional Partnerships and U.S. climate.

3.2.1 National Context

Atmosphere is defined as the mixture of gases surrounding any celestial object that has a gravitational field strong enough to prevent the gases from escaping, especially the gaseous envelope of Earth (Encarta, 2005a). Earth's atmosphere is comprised of nitrogen (N_2) (78 percent) and oxygen (O_2) (21 percent) with the remaining 1 percent comprised of argon (0.9 percent), CO_2 (0.03 percent), varying amounts of water vapor, and trace amounts of hydrogen (H_2), ozone, methane (CH_4), carbon monoxide (CO), helium, neon, krypton, and xenon (Encarta, 2005a).

The Earth's atmosphere is divided into several layers. The lowest region, the troposphere, extends from the Earth's surface up to about 6 miles (10 kilometers) in altitude. Virtually all human activities occur in the troposphere. The next layer, the stratosphere, continues from 6 to 30 miles above the surface (10 km to about 50 km). Most commercial airline traffic occurs in the lower part of the stratosphere. In the stratosphere, the chemical compound ozone plays a vital role in absorbing harmful ultraviolet radiation from the sun.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect" (Figure 1-1). Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 91°F lower (EPA, 2002a).

Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

3.2.1.1 Global Warming and Greenhouse Gases

Since the beginning of the Industrial Revolution, humans have been burning fossil fuels and conducting other activities, such as clearing land for agriculture or urban settlements, which release some of the same gases that trap heat in the atmosphere, including CO_2, CH_4, and N_2O. As these gases build up in the atmosphere, they trap more heat near the Earth's surface, causing Earth's climate to become warmer than it would naturally (Encarta, 2005b).

Although the Earth's atmosphere consists mainly of O_2 and N_2 neither play a significant role in promoting the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, CO_2, and other trace gases in the atmosphere that absorb terrestrial radiation leaving the surface of the earth (EPA, 2002a).

Naturally occurring GHGs include water vapor, CO_2, CH_4, N_2O, and O_3. Other halogenated substances are also GHGs but are primarily the products of industrial activities. Because CFCs, HCFCs and halons are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer, these gases are not included in national GHG inventories. There are several other gases that can affect the absorptive characteristics of the atmosphere. These tropospheric gases, referred to as ambient air pollutants, include: CO, nitrogen dioxide (NO_2), SO_2 and tropospheric (ground level) O_3.

CO_2, CH_4, and N_2O are continuously emitted to and removed from the atmosphere by natural processes on Earth. However, anthropogenic activities can cause additional quantities of these and other GHGs to be emitted or sequestered, changing their global average atmospheric concentrations.

A description of each GHG, its sources, and role in the atmosphere is provided below (EPA, 2002a).

CO_2 has an atmospheric lifetime between 50 and 200 years.

- **Water Vapor (H_2O):** Water vapor is the most abundant and dominant GHG in the atmosphere. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing (change in the balance between radiation coming into the atmosphere and radiation going out) produced by increased concentrations of other GHGs may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water-holding capacity. However, increased concentrations of water vapor affect the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Earth has an average albedo of 37 to 39 percent, which means that on average the Earth's surface, including the atmosphere and cloud cover, reflects these percentages of light radiation back into space.

- **Carbon Dioxide (CO_2):** In nature, carbon is cycled between various atmospheric, oceanic, terrestrial biotic, aquatic biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and oceans and, to a lesser extent, between the atmosphere and terrestrial biota. In the atmosphere, carbon predominantly exists in the oxidized form of CO_2, which has increased from approximately 280 ppm by volume in pre-industrial times to 367 ppm by volume in 1999, a 31 percent increase. CO_2 has an atmospheric lifetime between 50 and 200 years.

- **Methane (CH_4):** CH_4 is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal wastes. Methane is also emitted during the production and distribution of natural gas and petroleum and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH_4 have increased by about 150 percent since pre-industrial times, although the rate of increase has been declining. CH_4 is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2. Increasing emissions of CH_4 reduce the concentration of OH, a feedback that may increase CH_4's atmospheric lifetime (EPA, 2002a). CH_4, which has 21 times the 100-year GWP of CO_2, has an atmospheric lifetime between 9 and 15 years.

- **Nitrous Oxide (N_2O):** Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers, fossil fuel combustion (especially from mobile sources), nylon and nitric acid production, wastewater treatment, waste combustion and biomass burning. The atmospheric concentration of N_2O has increased 16 percent since 1750. N_2O is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere. Nitrous oxide has an atmospheric lifetime of approximately 120 years and has 310 times the 100-year GWP of CO_2.

- **Ozone (O_3):** Ozone is present in both the upper stratosphere and at lower concentrations in the troposphere (where it is the main component of smog). During the last two decades, CFCs and halons have depleted stratospheric O_3 concentrations and resulted in a change of the Earth's radiative energy. This change in the net radiative energy, or solar radiation energy, that enters and exits the atmosphere is termed a radiative forcing. The loss of O_3 in the stratosphere has resulted in negative radiative forcing. The depletion of the O_3 layer and radiative forcing was expected to reach a maximum around 2000 before starting to recover. The past increase in tropospheric O_3 is estimated to provide the third largest increase in radiative forcing since the pre-industrial era, after CO_2 and CH_4. Tropospheric O_3 is produced from the reactions of VOCs and NOx in the presence of sunlight.
- **Carbon Monoxide (CO):** Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric O_3 through chemical reactions with other atmospheric constituents that would otherwise assist in destroying these gases. CO is created when carbon-containing fuels are burned incompletely. Through natural processes, CO is eventually oxidized to become CO_2. Carbon monoxide concentrations are both short-lived and spatially variable.
- **Nitrogen Oxides (NO_x):** Nitrogen oxides are created by lightning, soil microbial activity, biomass burning, fuel combustion and in the stratosphere, the photo-degradation of N_2O. NO_x is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying degrees, NO_2 is the most common pollutant. The climate change effects of NO_x are indirect and the result of their promotion of formation of O_3 in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects. Concentrations of NO_x are both relatively short-lived and spatially variable.

As stated in Chapter 1, strong evidence is emerging that GHG emissions are linked to potential climate-change impacts. Concentrations of CO_2 in the atmosphere have increased rapidly in recent decades, and the increase correlates with the rate of world industrialization. In the last 100 years, atmospheric CO_2 concentrations have increased from approximately 280 ppm to nearly 380 ppm.

> The IPCC concluded that the warming in the northern hemisphere in the 20^{th} century is probably greater than any warming that has occurred during the past 1,000 years.

The IPCC concluded in 2001 that the warming of the northern hemisphere in the 20th century is probably greater than any warming that has occurred during the past 1,000 years and that most of the warming during the past 50 years is attributable to anthropogenic (human-caused) emissions of GHGs (EPA, 2004c). Graphics on the IPCC website (http://www.ipcc.ch/present/graphics/2001syr/large/05.16.jpg) depict temperature changes in the Northern Hemisphere over the last 1000 years. Greenhouse gases leave a distinctive "fingerprint" on climate, affecting temperature and precipitation in patterns that differ from those caused by fluctuations in solar output or natural variability (EPA, 2004c). As noted in Chapter 1 today's atmosphere contains 33 percent more GHGs than it did prior to the Industrial Revolution, and the concentration is increasing steadily at a rate of more than 1 ppm per year. It is generally recognized that anthropogenic GHG emissions are having a significant effect on global climate and that GHG emissions will need o be controlled to avoid future adverse climate impacts.

3.2.1.2 Climate

The Earth's climate has undergone many natural changes in the past, and it will continue to change naturally in the future. Today, however, there is another factor to consider. During the past century, people have burned millions of tons of fossil fuels to produce energy, releasing large quantities of GHGs and other substances that affect the climate (EPA, 2004a).

The U.S. is known for its diverse climates, which can be broken down into different climatic regions. The predominant climatic regions in the U.S. consist of Humid Continental – Warm Summer, Humid

Continental – Hot Summer, Humid Subtropical, Mediterranean, Marine West Coast, Semiarid, Desert, Subarctic, and Tundra, which are described below (Encarta, 2005d). Figure 3-1 represents the different climate regions across the U.S. and Alaska.

3.2.1.2.1 Humid Continental Climates

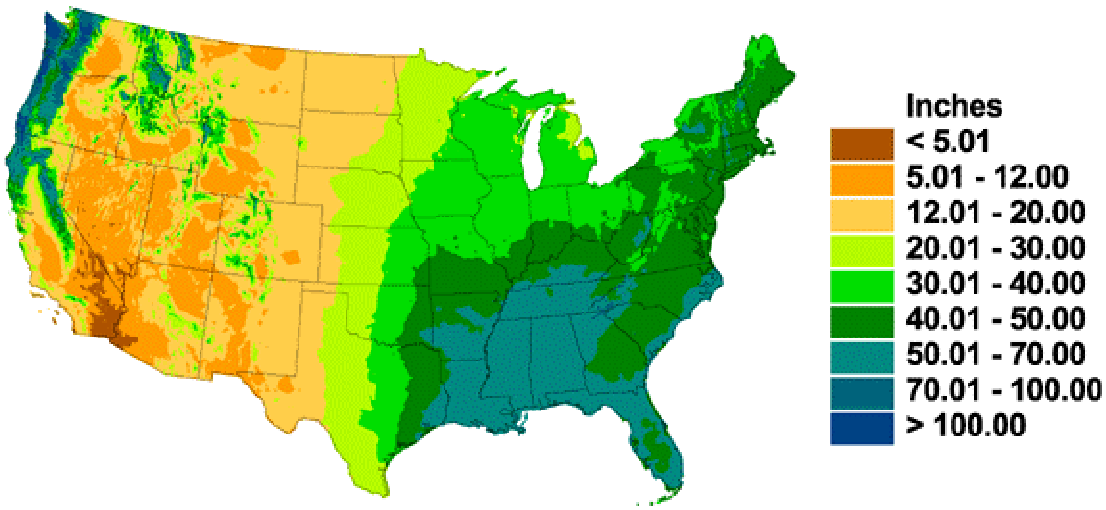
The eastern part of the U.S. is comprised of the Humid Continental and Humid Subtropical climate types. Humid Continental climate has two subtypes: those areas with hot summers and those with warm summers. The Humid Continental climates are transitional climates between the severe Subarctic climate region in Canada and the warmer Humid Subtropical region of the southern and southeastern U.S. These climates are mixing zones between cold polar air masses surging southward and tropical air moving northward.

3.2.1.2.2 Humid Continental (Hot Summer)

This subregion extends from the East Coast deep into the continental interior, south of the Great Lakes and is located between 35 and 45 degrees north latitude, it includes Rhode Island, Connecticut, Massachusetts, and southern New York, as well as New Jersey, Delaware, Maryland, Pennsylvania, West Virginia, Ohio, Indiana, Illinois, southern Wisconsin, and southern Michigan. In this climate zone, winters are cold and summers are hot. January temperatures usually average below 0°C (32°F), while July temperatures average between 18°C (65°F) and 24°C (75°F). Summers are humid with thunderstorms that may produce hail or tornadoes and annual precipitation averages from between 20 and 40 inches. Refer to Figure 3-2 for a map of the annual average precipitation for the U.S.

Source: USDA Forest Service, 2007.

Figure 3-1. United States Climate Regions



Source: NCDC, 2007

Figure 3-2. United States Annual Average Precipitation Map

3.2.1.2.3 Humid Continental (Warm Summer)

The "warm summer" subregion falls roughly from 45 degrees to 60 degrees north latitude and it lies astride the U.S.-Canadian border and includes most of the Great Lakes region. States in this climate region are Maine, New Hampshire, Vermont, upper New York, upper Michigan, northern Wisconsin, and Minnesota, as well as North Dakota, part of South Dakota, Montana, and sections of surrounding states. Winters in this area are harsh; snow remains on the ground for periods of up to five months. January average temperatures are less than -15°C (5°F) and summers are pleasantly cool, but short, with average monthly temperatures ranging from 18°C to 20°C (64°F to 68°F). Annual precipitation averages 32 inches. In the summer, precipitation is high when thunderstorms form along moving cold fronts and squall lines. Much of the winter precipitation is snow, which can remain on the ground for a couple of months at a time. The western area of prairie is a bit drier than the east.

3.2.1.2.4 Humid Subtropical

This climate region, characterized by long, hot, sultry summers, is found in the southeastern U.S. North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Florida, and portions of surrounding states are included in this climatic region. Temperatures average 26°C (80°F) in the summer and range from 4°C to 10°C (40°F to 50°F) in the winter. The Humid Subtropical climate receives ample precipitation, averaging about 30 inches annually in the western part of the region to more than 60 inches per year in the southern part. Most precipitation occurs in the summer months as rainfall. A polar air mass can push southward and bring an infrequent snowstorm, but snow seldom stays on the ground for more than a few days.

3.2.1.2.5 Semiarid

The Semiarid climates are found in sections of the Great Plains regions, parts of Texas, New Mexico, the intermontane basin of Nevada, parts of eastern Washington and Oregon, and sections of neighboring states. The temperature range is extreme. During winter the temperature can drop as low as -1°C (30°F) and summer temperatures often are in the upper 30°s C (lower 100°s F). Temperatures are considerably higher in Las Vegas, Nevada, located at the southern end of the region with the average July temperature being 32°C (90°F) and the average high temperature in January being in the lower 10°s C (lower 50°s F).

Annual rainfall is from 10 to 20 inches, which is enough to support grasses but not enough to maintain a forest cover.

3.2.1.2.6 Desert

The Desert climate region is found in the Southwest and includes southern inland California, Arizona, New Mexico, and parts of Nevada and Texas. The area receives less than 10 inches of rainfall annually and high temperatures cause any moisture to evaporate rapidly. Desert climates can be typically found on the dry side of mountain ranges. Mountains create a rain-shadow effect, with a belt of arid climate to the leeward side (the side opposite the prevailing winds) of the mountain barrier. Temperatures during the hottest months average from 29°C to 35°C (from 85°F to 95°F), and the midday readings of 40°C to 43°C (105°F to 110°F) are common (Encarta, 2005d). The winter daily maximum usually averages 18°C to 24°C (65°F to 75°F). Winter nights are chilly, averaging 7°C to 13°C (45°F to 55°F).

3.2.1.2.7 Mediterranean Climate

The Mediterranean climate of central and coastal California is characterized by dry summers and mild, rainy winters. Summer temperatures range from 20° to 25°C (68° to 77°F), and winter temperatures are a mild 4° to 10°C (40° to 50°F). The average precipitation of 360 millimeters (mm) to 640 mm (14 in to 26 in) per year occurs during the cool winter season and contrasts sharply to the area's dry summer months.

3.2.1.2.8 Marine West Coast

The Marine West Coast climate extends from northern California through the coastal sections of Oregon, Washington, and southern Alaska. Mild winters and summers distinguish this climate, even though inland climates at the same latitude have bitter winters and hot summers. In the Marine West Coast region, summer temperature averages range from 15°C to 20°C (from 59°F to 68°F), and the coldest months have a temperature range of 4°C to 10°C (40°F to 50°F). Winds out of the west bring in the moist air from the Pacific Ocean. Moist air rises over the mountainous Marine West Coast and releases its moisture. The result is high annual precipitation with extensive cloud development and profuse rainfall. The annual total rainfall may be as much as 57 inches, most of which falls during the winter months.

3.2.1.2.9 Subarctic

The Subarctic climate is found in most of interior Alaska, reaching as far north as the Arctic Circle (60° north latitude), where it gives way to a Tundra climate zone. Summer is very short in the climate region with temperatures averaging about 10°C (50°F) and winter starts as early as October with average temperatures of less than -15°C (5°F) for at least three or four months. Precipitation is usually less than 20 inches annually, and most falls as rain during the brief summer. Snow may accumulate to depths of 1 foot or more. Permanently frozen soil known as permafrost exists in the Subarctic climate. Permafrost requires that buildings be constructed to prevent heat losses because escaping heat can melt adjacent frozen subsoils, causing construction projects to slowly sink into saturated soils.

3.2.1.2.10 Tundra

The Tundra climate extends north of the Arctic Circle, from the Subarctic region to the Arctic Ocean. Like the Subarctic region, the Tundra experiences extremely long periods of daylight in the summer and extended periods of darkness during winter months. The average temperature for July, the warmest month, never exceeds 10°C (50°F). Annual precipitation is less than 14 inches, and much of the precipitation falls during the warm season in the form of rain or occasional wet snows. The meager winter snowfall is usually dry and powdery.

3.2.1.3 National Ambient Air Quality Standards

Air pollution is caused by a variety of sources. Industrial operations, cars and other modes of transportation, and natural sources such as volcanic eruptions and wildfires can emit a wide variety of pollutants. The U.S. EPA has established National Ambient Air Quality Standards (NAAQS) for 6 principal air pollutants (also called the criteria pollutants): NO_2, O_3, SO_2, particulate matter, CO, and lead (Pb). Table 3-1 provides estimates of major pollutant emissions from 1970 to 2003. Table 3-2 depicts the NAAQS.

Table 3-1. National Air Pollutant Emissions Estimates for Major Pollutants

	Millions of Tons Per Year								
	1970	**1975**	**1980**	**1985**	**1990**	**1995**	**20001**	**2002**	**2003[2]**
Carbon Monoxide (CO)	197.3	184.0	177.8	169.6	143.6	120.0	201.4	96.4	93.7
Nitrogen Oxides (NOx)[3]	26.9	26.4	27.1	25.8	25.1	24.7	22.3	20.8	20.5
Particulate Matter4 (PM-10)	12.2	7.0	6.2	3.6	3.2	3.1	2.3	2.4	2.3
Particulate Matter (PM2.5) [5]	NA	NA	NA	NA	2.3	2.2	1.8	1.8	1.8
Sulfur Dioxide (SO_2)	31.2	28.0	25.9	23.3	23.1	18.6	16.3	15.3	15.8
Volatile Organic Compounds (VOC)	33.7	30.2	30.1	26.9	23.1	21.6	16.9	15.8	15.4
Lead[6]	0.221	0.16	0.074	0.022	0.005	0.004	0.003	0.003	0.003
Totals[7]	301.5	275.8	267.2	249.2	218.1	188.0	160.2	150.2	147.7

Note: Fires and dusts excluded
1 In 1985 and 1996 EPA refined its methods for estimating emissions. Between 1970 and 1975, EPA revised its methods for estimating particulate matter emissions.
2 The estimates for 2003 are preliminary.
3 NOx estimates prior to 1990 include emissions from fires. Fires would represent a small percentage of the NOx emissions.
4 PM estimates do not include condensable PM, or the majority of PM-2.5 that is formed in the atmosphere from 'precursor' gases such as SO2 and NOx.
5 EPA has not estimated PM-2.5 emissions prior to 1990.
6 The 1999 estimate for lead is used to represent 2000 and 2003 because lead estimates do not exist for these years.
7 PM-2.5 emissions are not added when calculating the total because they are included in the PM-10 estimate.

Source: EPA, 2003.

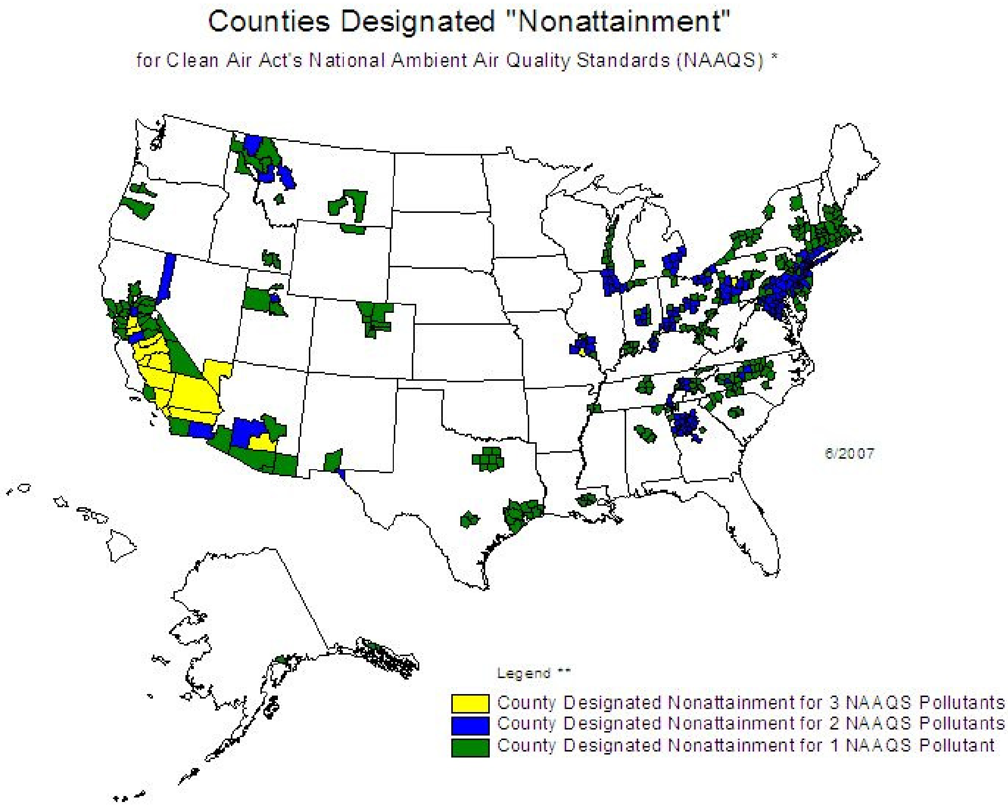
Table 3-2. National Ambient Air Quality Standards

Pollutant	Primary Standards	Averaging Times	Secondary Standards
Carbon Monoxide (CO)	9 ppm (10 mg/m)	8-hour	None
	35 ppm (40 mg/m)	1-hour	None
Lead (Pb)	1.5 µg/m	Quarterly Average	Same as Primary
Nitrogen Dioxide (NO_2)	0.053 ppm (100 µg/m)	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM-10)	50 µg/m	Annual (Arith. Mean)	Same as Primary
	150 µg/m	24-hour	
Particulate Matter (PM-2.5)	15.0 µg/m	Annual (Arith. Mean)	Same as Primary
	65 µg/m	24-hour	
Ozone (O_3)	0.08 ppm	8-hour	Same as Primary
	0.12 ppm	1-hour	Same as Primary
Sulfur Oxides (SO_x)	0.03 ppm	Annual (Arith. Mean)	-------
	0.14 ppm	24-hour	-------
	-------	3-hour	0.5 ppm (1,300 µg/m)

Source: EPA, 2004b.

3.2.1.3.1 EPA Designations

The EPA has designated geographical regions known as nonattainment areas when an area does not meet the air quality standard for one of the criteria pollutants. The area may be subject to the formal rulemaking process that designates the area as nonattainment. The 1990 Clean Air Act Amendments further classify O_3, CO, and some particulate matter nonattainment areas based on the magnitude of an area's problem (EPA, 2004b). Nonattainment classifications may be used to specify what air pollution reduction measures an area must adopt and when the area must reach attainment. Figure 3-3 depicts nonattainment status for different counties in the U.S.



Source: EPA, 2007.

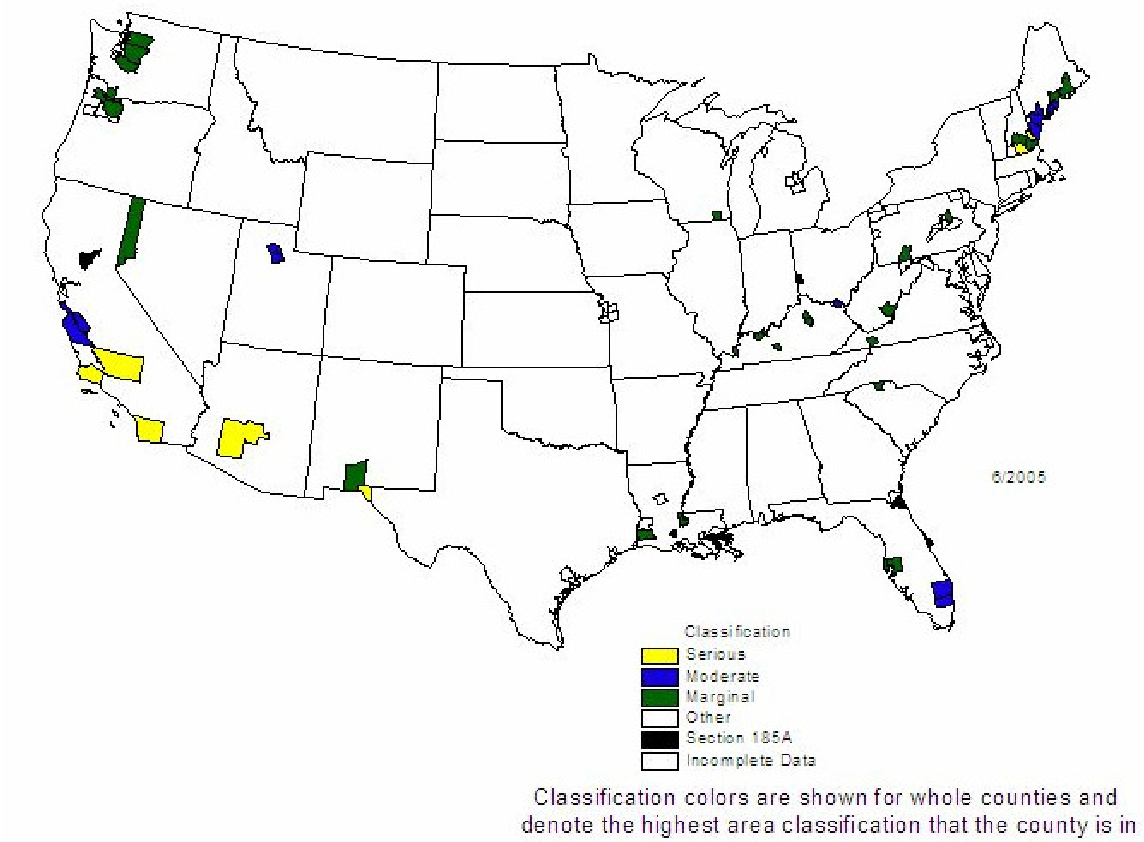
Figure 3-3. Counties Designated Nonattainment in the United States

3.2.1.3.2 Nitrogen Dioxide (NO_2)

NO_2 is a reddish brown, highly reactive gas that is formed in the ambient air through the oxidation of NO. Nitrogen oxides (NO_x), play a major role in the formation of O_3, PM, haze, and acid rain (EPA, 2004b). While EPA tracks national emissions of NO_x, the national monitoring network measures ambient concentrations of NO_2 for comparison to national air quality standards (EPA, 2002b). The major sources of man-made NO_x emissions are high-temperature combustion processes such as those that occur in automobiles and power plants (EPA, 2002b). There are no areas designated as nonattainment for NO_2.

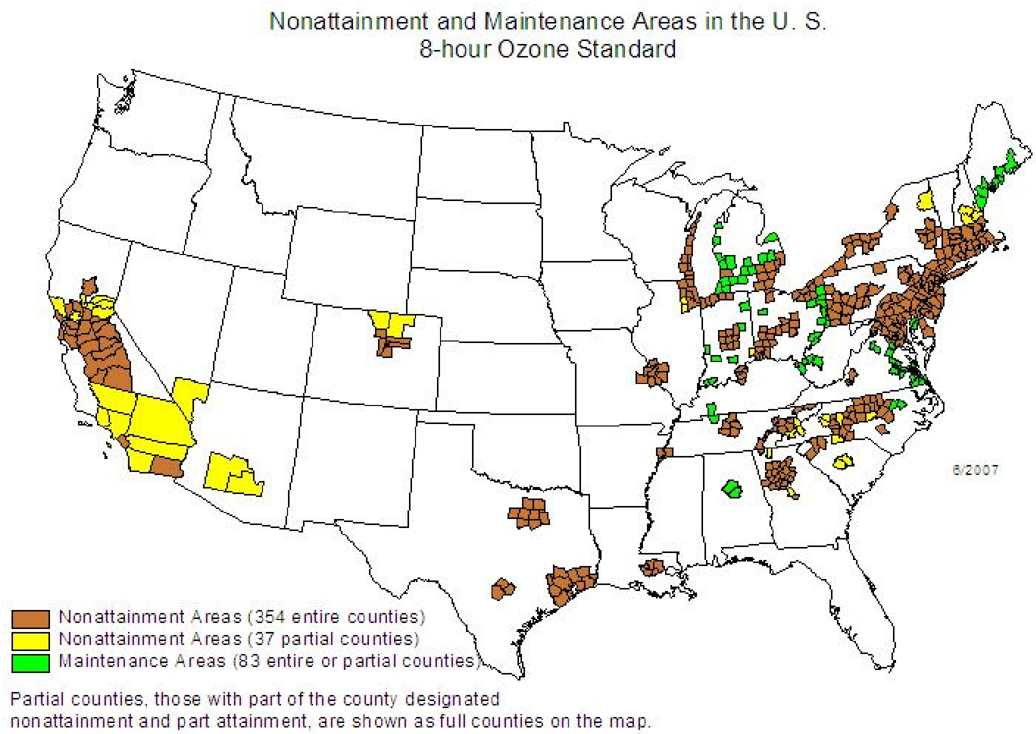
3.2.1.3.3 Ozone (O_3)

The pollutants that contribute to O_3 formation are NO_x and VOCs (EPA, 2002b). Some of the major sources of these pollutants are vehicle and engine exhaust, emissions from industrial facilities, combustion from electric utilities, gasoline vapors, chemical solvents, and biogenic emissions from natural sources (EPA, 2002b). Many urban areas tend to have higher levels of O_3, but even rural areas with relatively low amounts of local emissions may experience high O_3 levels because the wind transports O_3 and the pollutants that form it hundreds of miles away from their original sources (EPA, 2002b). Figure 3-4 and Figure 3-5 portray the 1-hour O_3 and 8-hour O_3 nonattainment status for counties in the U.S., respectively.



Source: EPA, 2004c.

Figure 3-4. One-Hour Ozone Nonattainment Areas in the United States

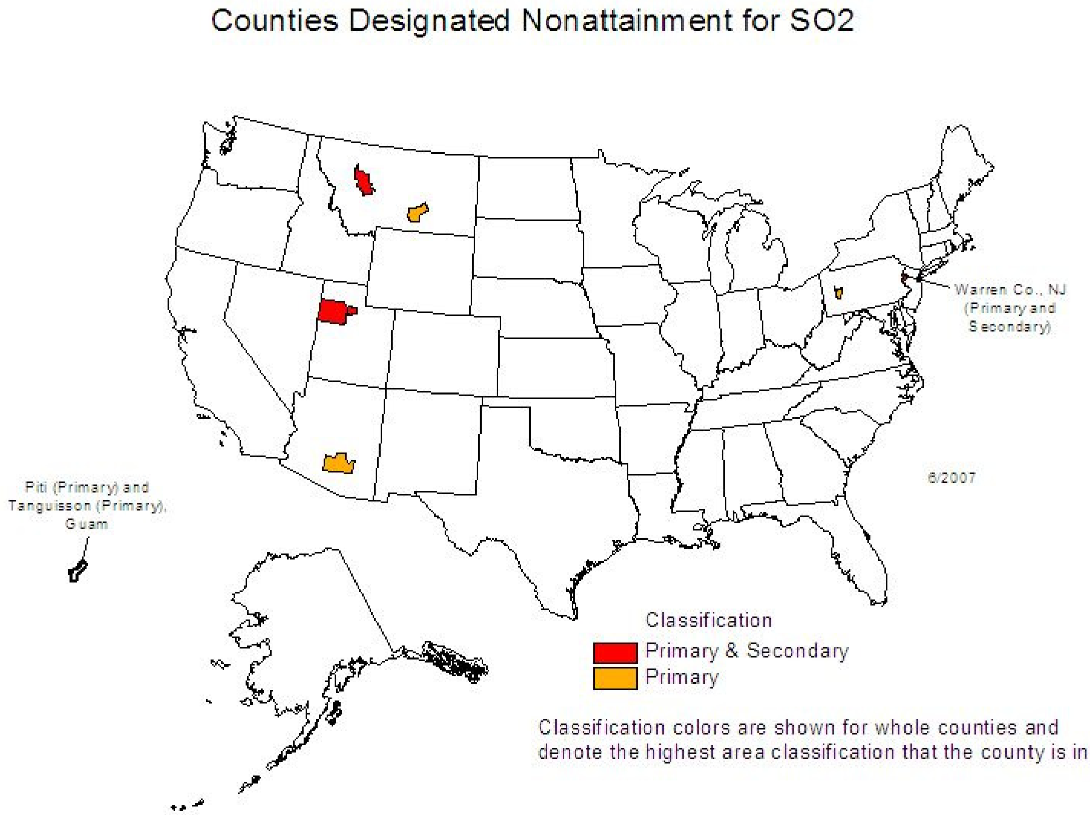


Source: EPA, 2007.

Figure 3-5. Eight-Hour Ozone Attainment and Nonattainment Areas in the United States

3.2.1.3.4 Sulfur Dioxide (SO_2)

SO_2 belongs to the family of SO_x gases. These gases are formed when fuel containing sulfur (primarily coal and oil) is burned at power plants and during metal smelting and other industrial processes (EPA, 2002b). Most SO_2 monitoring stations are located in urban areas with the highest monitored concentrations of SO_2 being recorded near large industrial facilities (EPA, 2002b). Fuel combustion, largely from electricity generation, accounts for most of the total SO_2 emissions. Figure 3-6 portrays areas designated nonattainment for SO_2.

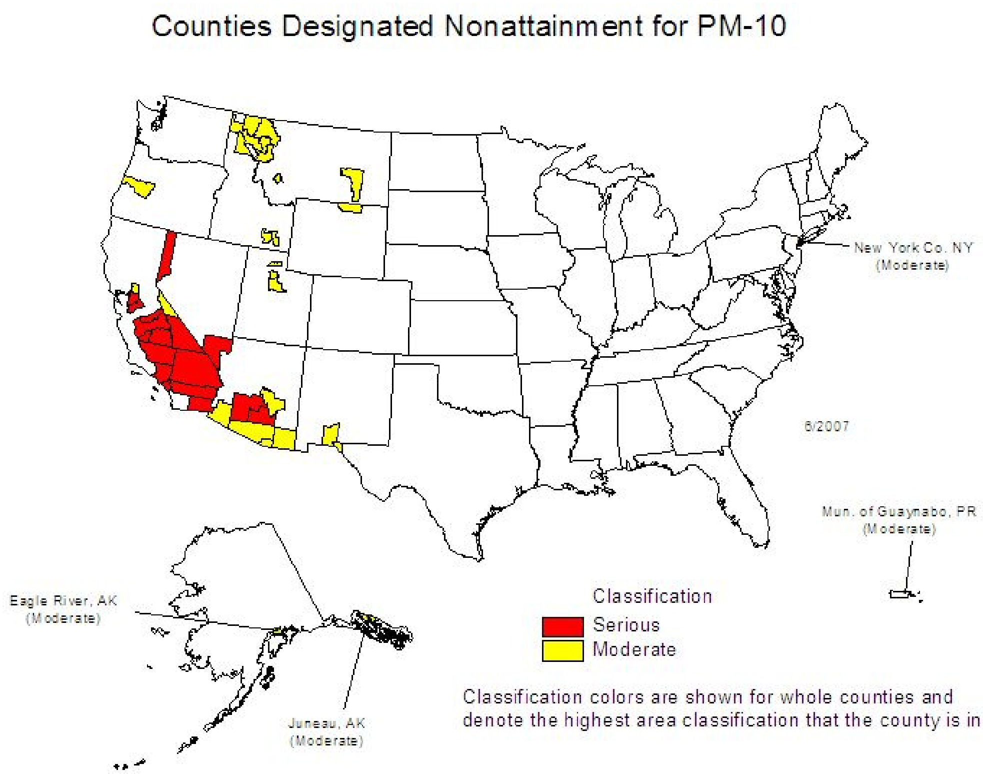


Source: EPA, 2007.

Figure 3-6. Counties Designated Nonattainment for Sulfur Dioxide in the United States

3.2.1.3.5 Particulate Matter (PM)

Particulate Matter is a mixture of solid particles and liquid droplets found in the air. Some particles are large enough to be seen as dust or dirt and others are so small they can be detected only with an electron microscope (EPA, 2002b). PM-2.5 describes the "fine" particles that are less than or equal to 2.5 micrometers (µm) in diameter. PM-10 refers to all particles less than or equal to 10 µm in diameter (about one-seventh the diameter of a human hair) (EPA, 2002b). "Primary" particles, such as dust from roads or black carbon (soot) from combustion sources, are emitted directly into the atmosphere and "secondary" particles are formed in the atmosphere from primary gaseous emissions. Examples include sulfates formed from SO_2 emissions from power plants and industrial facilities; nitrates formed from NO_x emissions from power plants, automobiles, and other combustion sources; and carbon formed from organic gas emissions from automobiles and industrial facilities (EPA, 2002b). Figure 3-7 shows counties designated nonattainment for particulate matter (PM-10).

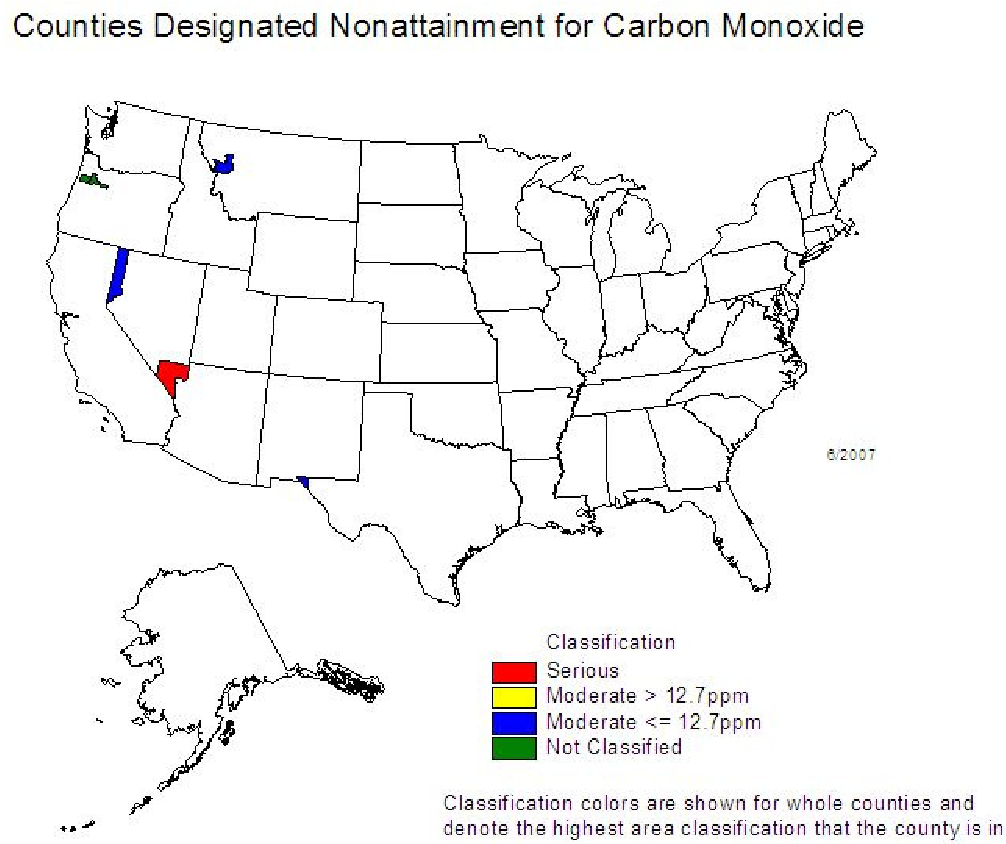


Source: EPA, 2007.

Figure 3-7. Counties Designated Nonattainment for Particulate Matter in the United States

3.2.1.3.6 Carbon Monoxide (CO)

CO is a colorless and odorless gas that is formed when carbon in fuel is not burned completely. It is a component of motor vehicle exhaust, which contributes about 60 percent of all CO emissions nationwide (EPA, 2002b). High concentrations of CO generally occur in densely populated areas with heavy traffic congestion. In cities, as much as 95 percent of all CO emissions may come from automobile exhaust (EPA, 2002b). Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources such as wildfires (EPA, 2002b). Peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are greater and nighttime inversion conditions (where air pollutants are trapped near the ground beneath a layer of warm air) are more frequent (EPA, 2002b). Figure 3-8 presents the counties within the U.S. that have nonattainment status for CO. The map shows serious CO emission problems in southern California and surrounding areas due in part to the wildfires in the southwestern states during 2003.



Source: EPA, 2007.

Figure 3-8. Counties Designated Nonattainment for Carbon Monoxide in the United States

3.2.1.3.7 Lead (Pb)

In the past, automotive sources were the major contributor of Pb emissions to the atmosphere. As a result of EPA's regulatory efforts to reduce the content of Pb in gasoline; however, the contribution of air emissions of Pb from the transportation sector, and particularly the automotive sector, has greatly declined over the past two decades (EPA, 2002b). Today, industrial processes, primarily metals processing, are the major source of Pb emissions to the atmosphere with the highest air concentrations of Pb usually being found in the vicinity of smelters and battery manufacturers (EPA, 2002b). Figure 3-9 presents counties designated nonattainment for Pb.

Source: EPA, 2007.

Figure 3-9. Counties Designated Nonattainment for Lead in the United States

3.2.1.4 State GHG Registries

EPA's State and Local Capacity Building Branch partners with states to develop GHG inventories and action plans. Forty-one states and Puerto Rico have completed inventories (See Figure A-1 in Appendix A). Each inventory identifies the major sources of GHG emissions and creates a baseline upon which reduction strategies are based. States play a critical role in reducing GHG emissions; many states have developed state action plans that draw heavily on the information in their inventories.

The inventories present annual emissions of GHG by sector (e.g., energy, agriculture, waste), by source (e.g., transportation emissions, manure management), and by gas (e.g., CO_2, CH_4). The methods on which the inventories are based generally estimate GHG emissions as a function of activity data (e.g., electricity usage, cement production, fertilizer consumption, etc.) and activity- and gas-specific emission factors.

Under Section 1605 of the Energy Policy Act of 1992, DOE through the Energy Information Administration (EIA) was directed to develop, based on data available, an inventory of the national aggregate emissions of each GHG between 1987 and 1990, and to issue guidelines for annual voluntary collection and reporting of information on sources of GHG emissions. On February 14, 2002, the President directed the Secretary of Energy, working with the Secretaries of Commerce and Agriculture, and the Administrator of the EPA, to propose improvements to the current GHG registry to "enhance measurement accuracy, reliability and verifiability, working with and taking into account emerging domestic and international approaches." On November 9, 2006, EIA submitted the "Voluntary Reporting of Greenhouse Gases, Form EIA-1605" to the Office of Management and Budget for review and a three-year extension under the Paperwork Reduction Act of 1995. A Federal Register Notice was issued on that date with comments requested by December 11, 2006. The revised reporting form, instructions, and Simplified Emissions Inventory Tool (SEIT) can be found at http://www.eia.doe.gov/oiaf/1605/forms.html. The revised guidelines emphasize the importance of providing a full accounting of all domestic and international GHG emissions, sequestration activities and emission reductions. The revised guidelines also include "state-of-the-science" guidance and tools for estimating emissions from agricultural, forestry, and conservation activities important for carbon sequestration efforts. The revised guidelines enable the DOE to recognize those participants in the program that provide an accurate and complete accounting of their GHG emissions and activities to reduce, avoid and sequester their GHG emissions. Under the revised guidelines, utilities, manufacturers and other businesses that emit GHGs will be able to register their emission reductions achieved after 2002 if they also provide entity-wide emissions inventory data (DOE, 2005).

3.2.2 State Air Quality

This section summarizes air quality for each state. Table 3-3 provides information on climate types, major sources of GHGs, and nonattainment areas for each state.

3.2.2.1 Alabama Air Quality Summary

Although improvements in air quality had been made in the early 1990s, monitoring data in the Birmington area since 1995 has shown nonattainment of the 1-hour O_3 standard. In 2001, there were 12 days exceeding the 8-hour O_3 standard and 3 days that exceeded the 1-hour O_3 standard. Ozone problems in Alabama are attributable to the southeastern U.S. having high natural VOC emissions, high temperatures, and a high probability of stagnation. Also, the Gulf Coast has land/sea breeze driven recirculation, stagnation, and convergence that concentrate and enhance reactivity of local emissions (Alabama, 2001).

3.2.2.2 Alaska Air Quality Summary

Alaska has experienced numerous exceedances of the PM-10 standard over the past twenty years and will continue to suffer from high levels of coarse fraction particulate well into the 21st Century. While the PM-10 problem in Southeast Alaska was primarily related to woodstove use, dust that was re-entrained from unpaved roads and winter traction sand did contribute to localized PM-10 exceedances. The summer of 2004 was the third driest summer on record, and wildfires burned the largest amount of acreage in recorded Alaska history (approximately 6.7 million acres). Smoke drifted over much of the state and concentrations were often in the "unhealthy," "very unhealthy," and "hazardous" ranges. Air Quality Alerts and Advisories were issued between June 28 and September 17, 2004 (Alaska, 2001).

3.2.2.3 Arizona Air Quality Summary

Concentrations of CO, lead and SO_2 have dramatically improved since requirements began in the 1970s, and all monitors for these pollutants have shown compliance with health standards in recent years. In April 2004, EPA designated a new 8-hour O_3 nonattainment area as encompassing the northeastern portion of Maricopa County and a very small portion of northeastern Pinal County. In September 2003, EPA issued a finding that the Phoenix metropolitan nonattainment area met a Dec. 31, 2000, deadline to comply with CO standards. The action moved the Phoenix metropolitan area a step closer to qualifying for designation as an attainment area for CO (Arizona, 2004).

3.2.2.4 Arkansas Air Quality Summary

Arkansas' most significant air pollution concern continues to be ground-level O_3 from pollutants common in metropolitan areas. However, days where air quality was unhealthy for sensitive groups for O_3, CO and PM dropped from 7 in 2002 to 1 in 2003. In 2003, Arkansas was in compliance with its 8-hour O_3 standard (Arkansas, 2003).

3.2.2.5 California Air Quality Summary

Air quality as it relates to O_3 has improved greatly in California over the last several decades, although not uniformly throughout the State. However, despite aggressive emission controls, maximum measured values exceed the national 1-hour O_3 standard in seven air basins and exceed the national 8-hour O_3 standard in 10 air basins. California's highest O_3 concentrations occur in the South Coast Air Basin, where the peak 1-hour indicator is close to two times the state standard. Ozone concentrations are generally lower near the coast than they are inland, and rural areas tend to be cleaner than urban areas. Most areas of California have either 24-hour or annual PM-10 concentrations that exceed the State standards. The highest annual average values of PM-10 during 2003 occurred in the Salton Sea, Great Basin Valleys, South Coast, San Joaquin Valley, and San Diego Air Basins. The State and national CO standards are now attained in most areas of California. The requirements for cleaner vehicles and fuels have been primarily responsible for the reductions in CO, despite significant increases in population and the number of vehicle miles traveled each day. However, there is still one problem area: the City of Calexico in Imperial County. While CO concentrations continue to decrease throughout most of the State, the CO problem in Calexico is unique in that this area shares a border with Mexico (California, 2005).

3.2.2.6 Colorado Air Quality Summary

For several years the Denver-metropolitan area had not violated any NAAQS for criteria pollutants. However, in the summer of 2003, ground level O_3 readings violated the new 8-hour standard and subsequently implemented an action plan to reduce O_3 levels. No violations of the PM-10, PM-2.5, or CO standards have occurred in the last 10 years. Studies have shown that the Denver Brown Cloud is caused by local, not regional emissions and have shown that chemical reactions in the atmosphere turn sulfates, nitrates and organic carbon into particles that cause the Brown Cloud. The largest single source of the Brown Cloud is motor vehicle use. Denver's meteorology and topography contribute to the Brown Cloud when pollutants are trapped in the Denver basin by air inversions (Colorado, 2004).

3.2.2.7 Connecticut Air Quality Summary

In 2004, 3 of 11 O_3 monitoring sites exceeded the level of the 1-hour ozone standard and 1 of 11 sites reported a fourth-highest daily 8-hour average O_3 concentration above the level of the 8-hour NAAQS. The number of monitoring sites recording 1-hour O_3 exceedances has varied between 3 and 11 (out of 11 total sites) per year between 1999 and 2004. These observed increases/decreases correspond to changing summer weather conditions. Warm and dry summers, with more frequent periods of air stagnation and/or pollution transport conditions, generally record increased exceedances of the ozone NAAQS. No exceedances of any other criteria pollutants were recorded in the state in 2004 (EPA, 2005).

3.2.2.8 Delaware Air Quality Summary

In 2004, there were several days when the 8-hour O_3 and PM2.5 standards were exceeded in Delaware. New Castle County has been designated non-attainment for PM2.5. There were no other exceedances of criteria pollutants in the state in 2004 (Delaware, 2004).

3.2.2.9 Florida Air Quality Summary

Florida is one of only 3 states east of the Mississippi River to meet all NAAQS. However, some areas of the state experience a few days each year when levels of ground-level O_3 or particles may be high enough to affect sensitive persons. There were 35 exceedances of the 8-hour standard in 2003; however, none have contributed to a violation of the standard (Florida, 2003).

3.2.2.10 Georgia Air Quality Summary

In 2004, Georgia had 19 exceedances of the 8-hour O_3 standard and 2 exceedances of the 1-hour O_3 standard. Georgia maintained compliance with all other NAAQS standards in 2004 (Georgia, 2004). In 2003, the only part of Georgia to not meet a NAAQS is the Atlanta Metropolitan 13 county non-attainment area (Clayton, Fulton, Rockdale, Cherokee, Gwinnett, Cobb, Forsyth, Dekalb, Fayette, Paulding, Douglas, Coweta, and Henry) for 1-hour O_3 (Georgia, 2003).

3.2.2.11 Hawaii Air Quality Summary

There have been no exceedances of any NAAQS in Hawaii over the last several years and most measurements show criteria pollutant levels well below national standards (EPA, 2006).

3.2.2.12 Idaho Air Quality Summary

The cities of Pocatello and Chubbuck typically experience high particulate levels (PM-10) from November to February. The air quality for the Portneuf Valley has consistently and dramatically improved over the past 10 years. The winter of 2002-2003 was the first where PM-10 levels were in the "good" category each day and PM-2.5 levels did not exceed the "moderate" category. The last recorded PM-10 air quality violation occurred in 1993 (Idaho, 2004).

3.2.2.13 Illinois Air Quality Summary

In 2002, air-monitoring equipment recorded six days when O_3 levels exceeded the 1-hour standard for O_3. Two of the days occurred in the Metro East region, and the remaining four occurred in the Chicago metropolitan area. According to the Air Quality Index (AQI), Illinois had 4 days when air quality was considered "red" or "unhealthy" and 34 days when air quality was considered "orange" or "unhealthy for sensitive groups" in one or more portions of the State in 2002. Of the 34 "orange" days, 30 were for 8-hour O_3, 11 were for PM-2.5 (fine particles), and 7 were both PM-2.5 and O_3 (Illinois, 2002).

3.2.2.14 Indiana Air Quality Summary

Indiana's air continues to improve. Emission reductions programs, that mandate stricter regulations for vehicles and industry, have reduced smog and dust levels. Indiana's air meets the NAAQS for SO_2, NO_2, CO, Pb, and PM-10 at air quality monitors located across the state. There are still areas and pollutants of concern to address. Some parts of Indiana still exceed the 1-hour O_3 standard and the 8-hour health standard for O_3 on some hot, sunny days. Air monitoring also shows that some areas of the state have levels of PM-2.5 that exceed the NAAQS. Levels of toxic chemicals, for which there are no federal health standards, are also of concern in Indiana (Indiana, 2004).

3.2.2.15 Iowa Air Quality Summary

Iowa has no areas designated nonattainment. In 2003, there was only one NAAQS exceedance. This exceedance was measured at Lake Sugema State Park for O_3 (Iowa, 2003). In 2004 there were 3 days where locations had AQI values over 100 due to PM, which is considered unhealthy for sensitive populations (Iowa, 2004).

3.2.2.16 Kansas Air Quality Summary

The ground level O_3 or smog problem develops in Kansas during the period from April through October due to high-pressure systems that stagnate in the summer months, characterized by cloudless skies, high temperatures and light winds. Upper air inversions also cause pollution concentrations to increase near the ground from pollution sources. Kansas has a long history of particulate matter problems caused by its weather. The Great Dust Bowl of the 1930s was caused in part by many months of minimal rainfall and high winds. Although this natural source of particulate matter pollution is still a concern today, it is not as severe as in the 1930s. Kansas has no areas in exceedance of the NAAQS (Kansas, 2004).

3.2.2.17 Kentucky Air Quality Summary

All Kentucky counties are currently in attainment of the standards for CO. There were no exceedances of any of the SO_2 standards in 2003. There were no exceedances of the NO_2 standard in 2003, and there have been no recorded exceedances of the NAAQS since the inception of sampling in 1970. Statewide and regional NO_2 levels show steady downward trends primarily due to the use of pollution control devices on motor vehicles, power plants and industrial boilers. In 2003 there were 25 exceedances of the 8-hour O_3 standard. Only preliminary attainment designations have been made based on 8-hour readings. All Kentucky counties are currently in attainment with the PM-10 standards. Statewide and regional PM-10 levels have shown declining trends. There were no exceedances of the 24-hour PM-2.5 standard in 2003. Five samplers exceeded the annual standard with four of those occurring in Jefferson County and the fifth in Fayette County (Kentucky, 2003).

3.2.2.18 Louisiana Air Quality Summary

In 2000, there were 8 days where one or more areas exceeded the 1-hour O_3 standard. Ground level O_3 presents a significant air quality problem in the Baton Rouge area during the summer months. Between 1990 and 1997, the Baton Rouge area experienced between 2 and 16 days each summer when federal air quality standards were violated (Louisiana, 2000).

3.2.2.19 Maine Air Quality Summary

There were no recorded exceedances of any NAAQS standards in Maine in 2004. Air monitoring for Pb has been discontinued because the concentration of lead in the air in Maine has been well below the NAAQS for many years (EPA, 2005).

3.2.2.20 Maryland Air Quality Summary

All of Maryland is in attainment for PM, NO_2, SO_2, Pb and CO. Large parts of Maryland are nonattainment for O_3 including Central Maryland, the Baltimore Metropolitan region, the Washington Metropolitan region, part of Southern Maryland and part of the Eastern Shore (Maryland, 2004).

3.2.2.21 Massachusetts Air Quality Summary

In 2004, 1 out of 15 monitoring sites measured O_3 levels above the NAAQS. Between 1999 and 2004 the number of monitoring sites recording O_3 levels above the NAAQS ranged from 1 to 11 (out of 15 total). This variation has been attributed differing summer weather conditions from year to year. No other exceedances of the NAAQS were recorded in 2004 (EPA, 2005).

3.2.2.22 Michigan Air Quality Summary

In 2003, all Michigan areas were in attainment with both the 1 hour and 8-hour CO standards. There are no large sources of Pb in Michigan and point source-oriented monitoring is not being conducted in the state. For Michigan, ambient NO_2 levels have always been well below the NAAQS (less than half).

When the monitoring data were averaged over a 3-year period between 1999 and 2003, there were only a total of 4 sites in all of Michigan that either met or were below the 8-hour O_3 standard. All areas of Michigan are in attainment with the PM-10 NAAQS since October 4, 1996. Overall, in 2003 there were seven PM-2.5 monitoring sites that were above NAAQS. These sites were all in Southeast Michigan. On October 20, 1982, the last remaining SO_2 nonattainment area in Michigan was redesignated to attainment (Michigan, 2003).

3.2.2.23 Minnesota Air Quality Summary

Annual averages of peak 1-hour and 8-hour O_3 concentrations are increasing at all monitoring sites in the Twin Cities, including a site in Blaine. Only at sites to the far north (Ely and Mille Lacs) are O_3 trends improving. Currently, Minnesota is in compliance with the new national air quality standard for O_3. However in the last two years, the Minnesota Pollution Control Agency has issued air pollution health alerts for O_3: four times in 2001, and once in 2002. These are the first alerts issued for O_3 since the 1970s. Over the five years from 1996 to 2000, CO_2 emissions from fossil fuel burning in Minnesota rose an average of 1.2 percent per year. These increases reflect a continuing increase in the electric utility and transportation sectors. From 1999 to 2000, CO_2 emissions increased 5.6 percent (Minnesota, 2003).

3.2.2.24 Mississippi Air Quality Summary

Based on 2001 to 2003 air monitoring data, all counties in Mississippi are attaining the new O_3 standard and on April 15, 2004, the EPA designated all counties in the state attainment with the 8-hour ground-level O_3 standard. Current monitoring data indicates that all areas of the state will attain the PM-2.5 standard (Mississippi, 2004).

3.2.2.25 Missouri Air Quality Summary

During 2002, Missouri met the NAAQS for O_3. In 2000, the Missouri Air Conservation Commission adopted a statewide rule to reduce NO_x emissions, intended to improve air quality in the St. Louis O_3 nonattainment area. Since 1993, facilities reduced PM-10 emissions by 59 percent, while VOC emissions dropped nearly 48 percent. SO emissions dropped 40 percent and NO_x emissions dropped 31 percent. There has been a 30 percent decrease in Pb emissions since 1993 (Missouri, 2002).

3.2.2.26 Montana Air Quality Summary

PM is Montana's major air pollution problem. The major sources of particulate are re-entrained road dust from passing vehicles on paved and unpaved roads, residential wood combustion, and industrial and agricultural activity. Since the promulgation of the PM-10 standards, several areas in Montana have been designated nonattainment including Butte, Columbia Falls, Kalispell, Libby, Missoula, Thompson Falls, and Whitefish. SO_2 is a pollutant of concern in the State and there are 4 areas in Montana where SO_2 is an issue. These are Great Falls in Cascade County, East Helena in Lewis & Clark County, Colstrip in Rosebud County; and the Billings/Laurel area in Yellowstone County. Pb is a pollutant of concern in East Helena where the predominant source is the ASARCO primary lead smelter. CO is a pollutant of concern in the larger communities in Montana and in West Yellowstone due to snowmobile activity in the winter. Currently, Missoula is categorized as “moderate” nonattainment for CO. All areas of the state are considered attainment for O_3 (Montana, 2003).

3.2.2.27 Nebraska Air Quality Summary

Of all pollutants monitored throughout the state in 2002, only Total Reduced Sulfur (TRS) exceeded its respective standards. The TRS standard was exceeded in Dakota City. TRS is not a NAAQS but a state standard. SO_2 measurements are well below the NAAQS. Although PM-10 exceedances have been recorded in Weeping Water in previous years, no exceedances were recorded in 2002. The O_3 NAAQS has never been exceeded at any site (Nebraska, 2002).

3.2.2.28 Nevada Air Quality Summary

Las Vegas Valley is designated a serious nonattainment area for CO and PM. The Truckee Meadows basin is designated as a moderate nonattainment area for CO and a serious nonattainment area for PM. Both areas experience elevated O_3 concentrations during the summer months. Anticipated standard changes may result in the classification of both areas as nonattainment for O_3. Because Nevada is a highly urbanized state, about 80 percent of the state's population lives within the PM and CO nonattainment areas (Nevada, 2001).

3.2.2.29 New Hampshire Air Quality Summary

There were no exceedances of the NAAQS in New Hampshire in 2004 and air pollution levels are well below primary and secondary NAAQS for CO, SO_2, NO_2, and PM10. In 1996 New Hampshire discontinued monitoring of Pb because historically Pb concentrations declined to the point where virtually no Pb was detectible at monitoring sites (EPA, 2005).

3.2.2.30 New Jersey Air Quality Summary

In 2003, New Jersey had numerous exceedances of the 1- and 8-hour O_3 NAAQS. Every county in New Jersey has been designated non-attainment for the 8-hour O_3 standard with the most severe ratings being in the northern and eastern regions of the state. There were no exceedances of any other criteria pollutants in 2003 (New Jersey, 2003).

3.2.2.31 New Mexico Air Quality Summary

Exceedances of EPA pollutant standards have occurred at 3 sites in the state. A small area around Sunland Park in Dona Ana County is designated non-attainment for O_3, at the lowest non-attainment level called marginal. An area around Anthony, also in Dona Ana County, is designated non-attainment for PM-10. This area, and other areas in Dona Ana County, experience high particulate levels during high wind events, especially in the spring and fall. Although the high levels occur because of natural events, the Bureau has put into place the Natural Events Action Plan (NEAP) in order to mitigate any man-made contributions such as uncontrolled construction sites. The third non-attainment area is located in Grant County, around the town of Hurley, where SO_2 standards were exceeded in the 1970s before the copper smelters installed control equipment. This area is soon to be designated in-attainment with the SO_2 standard (New Mexico, 2005).

3.2.2.32 New York Air Quality Summary

The Statewide PM-10 levels, SO_2 levels and CO levels in New York Levels are all below the ambient air quality standards (New York Department of Environmental Conservation, 2005a). The levels of ozone have been systematically declining in New York State during the past two decades. This decline is the result of motor vehicle exhaust emission controls, lower volatility fuels, stringent control of industrial pollution sources, and other measures that have reduced ozone precursors. Unhealthful ozone levels do still occur, however, particularly in New York City and the lower Hudson Valley. The NY Department of Environmental Conservation's (DEC) ozone monitoring network provides real-time information on ozone concentrations to the general public, and meets state and federal requirements. The ozone advisories are developed based on DEC's constant monitoring of ozone levels at 30 sites across the state. Recent results of ozone monitoring can be found in the New York State Ambient Air Quality Report. In addition, the DEP has been monitoring the ambient outdoor air for asbestos following the World Trade Center (WTC) disaster. This effort augmented ambient air asbestos sampling performed by the EPA and other state and city agencies (New York Department of Environmental Conservation, 2005b).

3.2.2.33 North Carolina Air Quality Summary

The EPA presented North Carolina its national Clean Air Excellence Award in March 2004 in recognition of the state's innovative Clean Smokestacks Act aimed at reducing multiple air pollutants. Under the act, coal-fired power plants must achieve a 77-percent cut in NO_x emissions by 2009 and a 73-percent cut in SO_2 emissions by 2013. These emissions cuts should lead to significant reductions in O_3, haze, fine particles and acid rain. Although the act does not set caps on mercury, the controls needed to meet the NO_x and SO_2 limits will reduce mercury emissions substantially. In 2000, there were 6 exceedances of the 1-hour standard, all of which occurred on three days in June. In 2000, the 8-hour standard was exceeded 239 times, on 35 different days, with 5 counties having 10 or more exceedances at individual sites (North Carolina, 2002).

3.2.2.34 North Dakota Air Quality Summary

There were no SO_2, NO_2, O_3 or PM exceedances of either the state or NAAQS measured during 2003. North Dakota is one of 14 states that are in attainment for all criteria pollutants. North Dakota has also been designated "attainment" for both the fine particulate and the 8-hour O_3 standards (North Dakota, 2004).

3.2.2.35 Ohio Air Quality Summary

SO_2 levels in urban areas have dropped an average of 16.7 percent in the last ten years. There were no violations of SO_2 air quality standards in 2003. All areas except Geauga County, which had 5 exceedances, are in attainment of the 1-hour O_3 standard. Two counties are in attainment of the 8- hour standard. There are 32 counties with monitored non-attainment based on data for 2001 through 2003. No violations of air quality standards for NO_2 were recorded in 2003 (Ohio, 2003).

3.2.2.36 Oklahoma Air Quality Summary

Data continues to indicate that O_3 levels have decreased from previous years in Oklahoma. Ozone monitors recorded exceedances of the 8-hour O_3 standard on 27 days in 2000, 15 days in 2001 and only 13 days in 2002 and 2003. All sites are in compliance with the PM-2.5 standard (Oklahoma, 2004).

3.2.2.37 Oregon Air Quality Summary

Motor vehicles are now the number one source of air pollution in Oregon. Emissions from cars contribute to ground level O_3 (smog) pollution especially on hot summer days. Smog is a problem in the Portland, Eugene, Salem and Medford areas. Oregon communities had minimal NAAQS exceedances and no violations (Oregon, 2003).

3.2.2.38 Pennsylvania Air Quality Summary

There were no exceedances of ambient air quality standards for PM-10 in 2001. Four sites exceeded the PM-2.5 24-hour standard in 2001. Pb levels have been in compliance for over 10 years. In 2001, averages for SO_2 were 50 percent below the annual ambient air quality standard. Ozone concentrations exceeded the 1-hour daily standard on 4 days and exceeded the 8-hour maximum daily level on 39 days during 2001. NO_2 levels have improved 11 percent between 1991 and 2001 and there were no exceedances of the standard in 2001. CO levels have improved 29 percent since 1992 and there were no exceedances of the standard in 2001 (Pennsylvania, 2001).

3.2.2.39 Rhode Island Air Quality Summary

In 2004, 2 of 3 ozone monitoring sites each reported one exceedance of the 1-hour O_3 NAAQS and 1 of 3 O_3 sites reported a fourth highest 8-hour average O_3 concentration exceeding the NAAQS. There were no other exceedances of any criteria pollutants in 2004 (EPA, 2005).

3.2.2.40 South Carolina Air Quality Summary

All areas of South Carolina were in attainment with the 1-hour O_3 standard in 2000. In fact, South Carolina is currently only one of 15 states meeting all NAAQS in 2000 (South Carolina, 2000).

3.2.2.41 South Dakota Air Quality Summary

South Dakota has no areas designated nonattainment. South Dakota is located in the high plains that is subject to periods of droughts and high winds. These are the main ingredients for fugitive dust problems. Fugitive dust is identified as dust from mining activity, gravel roads, construction activity, street sanding operations, and wind erosion from agricultural fields. Fugitive dust is the main problem in Rapid City (South Dakota, 2004).

3.2.2.42 Tennessee Air Quality Summary

Currently Tennessee has two counties (Knox, Hamilton) in violation of the PM-2.5 federal standard. Based on data for 2000 through 2002, a number of areas may not be in attainment of the 8-hour O_3 standard. A review of ambient O_3 data generated by the State of Tennessee's O_3 monitoring network from March 1, 2002 through October 31, 2002 shows the level of the old 1-hour standard of 0.12 ppm was exceeded at 1 site on 1 day and the level of the new 8-hour standard of 0.08 ppm was exceeded at numerous sites on 54 different days (Tennessee, 2002).

3.2.2.43 Texas Air Quality Summary

Four areas in Texas (Houston/Galveston/Brazoria, Beaumont/Port Arthur, Dallas/Fort Worth, and El Paso) are in nonattainment of the 1-hour O_3 standard. Ozone formation tends to be highest from March through October in Texas. In 2004, there were 41 days where the 1-hour O_3 standard was exceeded by one or more areas (Texas, 2004).

3.2.2.44 Utah Air Quality Summary

Utah is in compliance with both the 1-hour and the 8-hour O_3 standard and meets federal standards for both PM-10 and PM-2.5. Nevertheless, high concentrations of particulate matter are brought on by wintertime episodes of air stagnation and temperature inversion. As such, there are periods during the winter months when ambient concentrations approach the standards. In 2003, Utah submitted a plan to the EPA showing that Utah County would continue to show compliance with the federal PM-10 standards for the next ten years. Utah was in compliance with the CO standards in 2003 (Utah, 2003).

3.2.2.45 Vermont Air Quality Summary

In 2004, there were no exceedances of any NAAQS. Vermont did not conduct monitoring for Pb in 2004 because historical concentrations of Pb have been extremely low (EPA, 2005).

3.2.2.46 Virginia Air Quality Summary

In 2004, there were 2 days where one or more areas exceeded the 1-hour O_3 standard. These exceedances occurred in Alexandria, Fairfax County and Loudoun County in July. There were 6 days where the 8-hour O_3 standard was exceeded. These exceedances occurred in the time period May to July in 12 counties (Virginia, 2004).

3.2.2.47 Washington Air Quality Summary

From the period 1999 to 2002, there was one exceedance of the PM-10 standard each year. There was one exceedance of the 8 hour O_3 standard at Enumclaw for both 2000 and 2001. There were no exceedances of CO between 2000 and 2002. EPA designated the central Puget Sound and Vancouver areas nonattainment for the 1-hour O_3 standard. Both standards apply to Washington until June 15, 2005. On that date, EPA will revoke the 1-hour standard and leave the 8-hour standard as the sole O_3 standard. Washington must submit maintenance plans to EPA for the central Puget Sound and Vancouver areas by June 15, 2007 (Washington, 2004).

3.2.2.48 West Virginia Air Quality Summary

Ground-level O_3 is one of West Virginia's recurring air pollution problems. All monitoring sites have shown consistent averaged values that are well below the 24-hour and annual PM-10 NAAQS. Berkeley, Brooke, Cabell, Hancock, Jefferson, Kanawha, Marion, Marshall, Ohio, Putnam, Wayne, and Wood counties do not meet the PM-2.5 NAAQS. Over the last decade, the annual average SO_2 level in the ambient air has been well below the standard. In 2003, all sites except one reported levels below the 1-hour and the 8-hour standard for CO (West Virginia, 2003).

3.2.2.49 Wisconsin Air Quality Summary

There was only one Ozone Action Day in 2004 in Wisconsin (Wisconsin, 2004). However, Wisconsin issued its first statewide air health advisory on February 1, 2005 based on the presence of persistently elevated levels of fine particles in the air, recorded at seven air quality monitoring stations located around the state (Wisconsin, 2005). The combination of moist, warm air with stagnant weather conditions, together with the input of particulate emissions from power plants, motor vehicle operation and other fuel burning sources led to the Orange level health advisory. At the same time, similar advisories were issued in number of Ohio cities, six Indiana counties, and in Minnesota, Iowa, Illinois and Pennsylvania.

3.2.2.50 Wyoming Air Quality Summary

Wyoming has no nonattainment areas, however, the state is developing a long-term plan to improve air quality.

Table 3-3. Climate Types, Major Sources of GHGs, and Nonattainment Areas in the States

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Alabama	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (98%), the majority of which is due to transportation petroleum and utility coal. Minor emissions came from cement production, lime manufacture, and limestone use (2%). Carbon dioxide sinks (non-fuel usage, timber stock, and other forest resources) offset about 17%of the total CO_2 emissions. Sources of CH_4 emissions were coal mining (57%), landfills (27%), domesticated animals (9%), manure management (4%), natural gas/oil extraction (3%), fossil fuel combustion (<1%), and wastewater (<1%). N_2O emissions were attributable to fossil fuel combustion (61%), and agricultural soils (39%).	PM-2.5 (1) 8-Hour O_3 (1)
Alaska	Marine West Coast/Subarctic/ Tundra	N/A	PM-10 (2)
Arizona	Semiarid/ Desert	N/A	PM-10 (8) SO_2 (4)
Arkansas	Humid Subtropical	N/A	None

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
California	Marine West Coast/ Mediterranean/ Desert	CO_2 accounted for the majority of California's emissions. These emissions were primarily due to the burning of fossil fuels, especially in the transportation sector (about 52 percent of total CO_2 emissions). Nitrous oxide (N_2O) emissions fluctuated between 1990 and 2002, with the majority of these emissions from agricultural soils and mobile source combustion. Over the 13-year period, emissions from agricultural soils generally increased while emissions from mobile source combustion generally decreased. CH_4 was the third largest contributor to California's emissions in 1990 and in 2002, equal to 8.5 MMTCE in both years. CH_4 emissions were fairly constant over the time period and were mostly from landfills and enteric fermentation. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) each made up a small share of the total emissions. These emissions increased between 1990 and 2002, with 2002 emissions of these gases approximately 74% above 1990 levels. This increase in HFC/PFC/SF6 emissions is largely due to the replacement of ozone-depleting substances (CFCs) with HFCs, which have high global warming potentials.	PM-2.5 (2) PM-10 (10) CO (1) 8-Hour O_3 (15)
Colorado	Semiarid	The major source of CO_2 emissions was fossil fuel combustion (99%), with minor emissions from land use, lime manufacture, and cement manufacturing (1%). Contributors to CH_4 emissions were domesticated animals (45%), coal mining (23%), landfills (18%), oil and natural gas systems (11%), and minor emissions from manure management and wastewater treatment (3%). The sole source of N_2O emissions were fertilizer use.	8-Hour O_3 (1)
Connecticut	Humid Continental (Hot Summer)	CO_2 accounted for the majority of Connecticut's emissions. These emissions were mostly due to the burning of fossil fuels, primarily for transportation; electricity production; and energy consumption in the residential sector. CH_4 was the second largest contributor to Connecticut's emissions in 1990 and in 2000, equal to 0.8 and 0.5 MMTCE respectively. CH_4 emissions decreased slightly over the time period; these emissions resulted from the anaerobic decay of solid waste in landfills and, to a lesser extent, emissions from natural gas and oil systems. N_2O emissions were fairly constant, amounting to 0.4 MMTCE in 1990 and 2000, and were mostly from mobile source combustion and waste combustion. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) each comprised a small share of the total emissions. These emissions increased from 0.1 to 0.2 MMTCE between 1990 and 2000. This increase in HFC/PFC/SF6 emissions is largely due to the replacement of ozone-depleting substances (CFCs) with HFCs, which have high global warming potentials.	8-Hour O_3 (1)
Delaware	Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (>99%), with minor emissions from agricultural application of lime, and lime manufacture. Almost half of the emissions from fossil fuel combustion came from the utility sector. Combustion of fossil fuels accounted for over 95% of total greenhouse gas emissions. Contributors to CH_4 emissions were landfills (76%), manure management (14%), domesticated animals (8%), and municipal wastewater (2%). N_2O emissions were attributable to fertilizer use. Delaware did not evaluate sources and sinks (i.e., an increase in forest carbon storage) associated with land use.	None
District of Columbia	Humid Continental (Hot Summer)	N/A	PM-2.5 (1) 8-Hour O_3 (1)
Florida	Humid Subtropical	The only source of CO_2 emissions evaluated in the inventory was fossil fuel combustion. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 5% of the total CO_2 emissions. Sources of CH_4 emissions were landfills (75%), domesticated animals (19%), and manure management (6%). Nitrous oxide emissions were attributable to agricultural soil management (81%) and manure management (19%). Emissions of HFCs, PFCs, and SF_6 were due to the use of substitutes for O_3 depleting substances.	None

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Georgia	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (98%), with minor emissions from cement production, limestone use, and soda ash consumption. In particular, coal used for utilities accounted for 41% of emissions from fossil fuel combustion, and use of petroleum for transportation comprised of 37% of emissions from fossil fuel combustion. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 11% of the total CO_2 emissions. Contributors to CH_4 emissions were waste (52%), manure management (28%), domesticated animals (15%), natural gas systems (5%), and burning of agricultural waste (<1%). The sources of N_2O emissions were fertilizer use and the burning of agricultural waste.	PM-2.5 (3) 8-Hour O_3 (3)
Hawaii	Tropical Rain Forest	The major source of CO_2 emissions was fossil fuel combustion (99%) with minor emissions (<1%) from cement production and waste combustion. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 6% of the total carbon dioxide emissions. Contributors to methane emissions included landfills (57%), fossil fuel combustion (20%), domesticated animals (14%), manure management (6%), wastewater treatment (1%), and agricultural burning (<1%). The sources of N_2O emissions were fossil fuel combustion (83%), agricultural soils management (16%), the burning of agricultural waste (<1%), and waste combustion (<1%).	None
Idaho	Humid Continental (Warm Summer)	N/A	PM-10 (5)
Illinois	Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (99%), the majority of which is due to transportation petroleum and utility coal. Illinois estimated emissions associated with land use, but did not estimate land use-related sinks (i.e., an increase in forest storage carbon), which most states (and nationally) far exceed emissions. Sources of CH_4 emissions were landfills (66%), coal mining and natural gas production (23%), manure management (7%), and domesticated animals (4%). Nitrous oxide emissions were attributable to fertilizer use.	PM-2.5 (2) 8-Hour O_3 (2)
Indiana	Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (99%) with minor emissions from cement production (<1%). Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 1% of the total CO_2 emissions. Contributors to CH_4 emissions included landfills (47%), manure management (18%), domesticated animals (15%), coal mining (10%), natural gas production (8%), and fossil fuel combustion (3%). Nitrous oxide emissions were accounted for by fertilizer use (77%) and fossil fuel combustion (23%).	PM-2.5 (6) 8-Hour O_3 (4)
Iowa	Humid Continental (Warm Summer/Hot Summer)	The majority of Iowa's emissions came from CO_2, with the burning of fossil fuels, primarily for the production of electricity, constituting the majority of the CO_2 emissions in both years. There was a significant emissions increase in N_2O between 1990 and 2000, which was a result of a change in methodology for calculating soil emissions. Adequate soil data was not available to recalculate the 1990 estimate. It is unlikely that actual soil emissions varied significantly between the two years, though more sources of soil emissions were identified. CH_4 was the second largest contributor to Iowa's emissions in 1990 and third largest contributor in 2000. These emissions were mostly from landfills, manure management, and domesticated animals. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) each comprised a small share of the total emissions as well.	None

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Kansas	Semiarid/ Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (85%), most of which (70%) was accounted for by the electric utility and transportation sectors. Contributors to CH_4 emissions included domesticated animals (76%), landfills (12%), manure management (7%), and minor emissions from mining and extraction of natural gas, oil, and coal, and wastewater treatment. Sources of N_2O emissions included fertilizer use (90%) and industrial processes (10%). Kansas did not evaluate sources and sinks (i.e., an increase in forest carbon storage) associated with land use.	None
Kentucky	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (96%), the majority of which is utility coal. Minor emissions came from cement and lime production and forest/grassland conversion. Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 26% of the total CO_2 emissions. Sources of CH_4 emissions were coal mining (73%), domesticated animals (12%), landfills (10%), manure management (3%), and natural gas/oil extraction (2%). Nitrous oxide emissions were from fertilizer use. Sources of perfluorocarbons were HCFC-22 production (91%) and aluminum production (9%).	PM-2.5 (2) 8-Hour O_3 (3) SO_2 (1)
Louisiana	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (99%), with minor emissions from lime manufacture, limestone use, CO_2 production, electric utilities and semiconductors, and agricultural soil management. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 10% of the total CO_2 emissions. Sources of CH_4 emissions were natural gas and oil extraction (51%), landfills (25%), rice cultivation (14%), domesticated animals (9%), and manure management (1%). N_2O emissions were attributable to nitric acid production (61%) and agricultural soil management (39%). Emissions of HFCs and SF_6 were due to HCFC-22 production and electric utilities and semiconductors.	8-Hour O_3 (1)
Maine	Humid Continental (Warm Summer)	The major source of carbon dioxide emissions was fossil fuel combustion (99%), with minor emissions from cement production (<1%). Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 12% of the total carbon dioxide emissions. Contributors to methane emissions were landfills (84%), domesticated animals (11%), manure management (2%), fossil fuel combustion (2%), and wastewater (1%). Fertilizer use (99%) and fossil fuel combustion (1%) accounted for nitrous oxide emissions.	8-Hour O_3 (2)
Maryland	Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (97%), with minor emissions from land-use conversion (2%) and from cement production and lime manufacture (1%). Fossil fuel combustion for transportation and utilities comprised over 65% of the CO_2 emissions from fossil fuel combustion, primarily from use of coal and petroleum. Contributors to CH_4 emissions were landfills (60%), manure management (15%), coal mining (13%), domesticated animals (10%), and fossil fuel combustion (2%). Nitrous oxide emissions were accounted for fuel combustion (2%). Nitrous oxide emissions were accounted for by fossil fuel combustion (87%) and fertilizer use (13%).	PM-2.5 (2) 8-Hour O_3 (3)
Massachusetts	Humid Continental (Hot Summer)	The major source of carbon dioxide emissions was fossil fuel combustion (98%). Emissions from waste combustion (2%) and lime manufacturing and limestone use (<1%) comprised the remainder of the carbon dioxide emissions. Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 10% of the total carbon dioxide emissions. Contributors to methane emissions included landfills (91%), domesticated animals and manure management (4%), fossil fuel combustion (3%) and wastewater treatment (2%). The primary source of nitrous oxide emissions was fossil fuel combustion (>99%), with minor emissions from fertilizer use (<1%).	8-Hour O_3 (2)

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Michigan	Humid Continental (Hot Summer)	CO_2 accounted for the vast majority of Michigan's emissions. These emissions were due in large part to the burning of fossil fuels, primarily for transportation and the production of electricity. CH_4 was the next largest contributor, mostly from the anaerobic decay of solid waste in landfills. N_2O, the third largest contributor, came chiefly from agricultural soil management and mobile source combustion. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) each made up a small share of the total emissions as well. The increase in HFC/PFC/SF6 emissions in 2002 was largely a result of the replacement of ozone-depleting substances (CFCs) with HFCs, which have high global warming potentials.	PM-2.5 (1) 8-Hour O_3 (12)
Minnesota	Humid Continental (Warm Summer)	The major source of CO_2 emissions was fossil fuel combustion (>99%), with minor emissions from waste combustion, limestone use, CO_2 manufacture, and agricultural soils (<1%). Of those CO_2 emissions from fossil fuel combustion, 79% were attributable to coal use for the utility sector and petroleum use for transportation. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 10% of the total CO_2 emissions. Contributors to CH_4 emissions were landfills (39%), domesticated animals (39%), manure management (13%), natural gas and oil systems (7%), fossil fuel combustion (1.9%), and rice cultivation (<1%). The majority of N_2O emissions were from fertilizer use (80%), with minor emissions from fossil fuel combustion (19%), and waste combustion (1%).	None
Mississippi	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (99.5%), the majority of which is transportation petroleum. CO_2 emissions and sinks resulting from land use were estimated in this inventory, however, they are not included in this summary because Mississippi did not break out forest and land use changes by type of forest as described in the workbook methodology. Sources of CH_4 emissions included agricultural burning (43%), landfills (26%), domesticated animals (21%), manure management (7%), and rice cultivation (3%). N_2O emissions were accounted for by fertilizer use (95%) and agricultural burning (5%).	None
Missouri	Humid Continental (Hot Summer)/Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (97%), with minor emissions from cement and lime manufacturing. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 19% of the total CO_2 emissions. Sources of CH_4 emissions were domesticated animals (43%), manure management (28%), landfills (24%), natural gas production (4%) and fossil fuel combustion (1%). N_2O emissions were primarily attributable to fertilizer use (61%), fossil fuel combustion (28%), and nitric acid production (10%). Emissions of perfluorocarbons were entirely attributable to aluminum production.	PM-2.5 (1) Lead (1) 8-Hour O_3 (1)
Montana	Humid Continental (Warm Summer)	The major source of CO_2 emissions was fossil fuel combustion (99%), with minor emissions from cement manufacture and lime manufacture. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 54% of the total CO_2 emissions. Contributors to CH_4 emissions were domesticated animals (68%), landfills (22%), natural gas and oil production (7%), coal mining (3%), and wastewater (<1%). N_2O emissions were entirely attributable to fertilizer use. Emissions of perfluorocarbons were entirely attributable to aluminum production.	PM-10 (10) Lead (1) SO_2 (1) CO (1)
Nebraska	Humid Continental (Warm Summer)	N/A	None
Nevada	Desert/ Semiarid	The major source of CO_2 emissions was fossil fuel combustion (97%), with minor emissions from industrial processes (3%). Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 1% of the total CO_2 emissions. Contributors to CH_4 emissions included domesticated animals (50%), landfills (35%), natural gas processing, transmission, and distribution (9%), manure management (5%), and minor emissions from wastewater treatment and agricultural waste burning (1%). All N_2O emissions were accounted for by fertilizer use.	PM-10 (2) CO (2) 8-Hour O_3 (1)

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
New Hampshire	Humid Continental (Warm Summer)	The major source of CO_2 emissions was fossil fuel combustion (>99%) with minor emissions (<1%) from limestone used in agricultural soils and paper manufacturing; and soda ash used in paper manufacturing, glass and textile production, and water treatment. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 30% of the total CO_2 emissions. Contributors to CH4 emissions included landfills (84%), domesticated animals (8%), natural gas pipelines (3%), manure management (2%), fossil fuel combustion (2%), and wastewater treatment (<1%). N_2O emissions were accounted by fossil fuel combustion (97%) and fertilizer use (3%).	8-Hour O_3 (1)
New Jersey	Humid Continental (Hot Summer)	The only source of CO_2 emissions was fossil fuel combustion, with transportation petroleum accounting for about 50% of those emissions. Sources of CH_4 emissions were landfills (90%), natural gas and oil extraction (8%), domesticated animals (1%), wastewater (1%), and manure management (<1%). N_2O emissions were from nitric acid production (88%) and fertilizer use (12%). All sulfur hexafuoride emissions were from electric utilities. New Jersey did not evaluate sources and sinks (i.e., an increase in forest carbon storage) associated with land use.	PM-2.5 (2) 8-Hour O_3 (2)
New Mexico	Semiarid/ Desert	The major source of CO_2 emissions was fossil fuel combustion (more than 99%), with minor emissions from cement production. New Mexico generates a large amount of electricity, primarily from coal, for export to neighboring states. Thus, utility coal accounted for almost 50% of CO_2 emissions from fossil fuel combustion. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 7% of the total CO_2 emissions. Contributors to CH_4 emissions were natural gas and oil systems (48%), waste (22%), domesticated animals (19%), manure management (7%), and coal mining (4%). The source of N_2O emissions was fertilizer use.	PM-10 (1)
New York	Humid Continental (Hot Summer)	The major source of carbon dioxide emissions was fossil fuel combustion (99%), the majority of which is due to transportation petroleum. Minor emissions came from cement production (<1%). Carbon dioxide sources or sinks from forest resources were not estimated in this inventory. Sources of methane emissions were landfills (93%), domesticated animals (5%), fossil fuel combustion (1%), and manure management (<1%). Nitrous oxide emissions were accounted for by fossil fuel combustion (84%), and fertilizer use (16%).	8-Hour O_3 (8) PM-10 (1) PM-2.5 (1)
North Carolina	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (99%) with minor emissions (<1%) from lime processing, agricultural use of limestone, and waste combustion. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 8% of the total CO_2 emissions. Contributors to CH_4 emissions included manure management (49%), landfills (38%), domesticated animals (6%), fossil fuel combustion (5%), natural gas systems (1%), and agricultural burning (<1%). Nitrous oxide emissions were accounted for by fossil fuel combustion (54%), fertilizer use (46%), and agricultural burning (<1%).	PM-2.5 (2) 8-Hour O_3 (7)
North Dakota	Humid Continental (Warm Summer)	N/A	None
Ohio	Humid Continental (Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (99%), with minor emissions from cement production, lime manufacture and waste combustion. Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 2% of the total CO_2 emissions. Sources of CH_4 emissions were landfills (83%), coal mining (7%), domesticated animal (5%), manure management (3%), and agricultural residue burning (2%). Nitrous Oxide emissions were attributable to agricultural soil management (88%) and agricultural residue burning (12%). Emissions of CFCs were due to HCFC-22 production.	PM-2.5 (8) 8-Hour O_3 (11)

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Oklahoma	Semiarid/ Humid Subtropical	CO_2 accounted for the majority of Oklahoma's emissions; these emissions were primarily due to burning of fossil fuels for the production of electricity and, to a lesser extent, combustion for the transportation and industrial energy sectors. Other sources made minor contributions to CO_2 emissions. CH_4 was the next largest contributor, resulting from natural gas and oil systems, enteric fermentation, and manure management. N_2O, the third largest contributor, came chiefly from agricultural soil management. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) from industrial processes each made up a small share of the total emissions as well. The increase in HFC/PFC/SF6 emissions in 1999 was largely a result of the replacement of ozone-depleting substances (CFCs) with HFCs, which have high global warming potentials.	None
Oregon	Marine West Coast/Semiarid	The major source of CO_2 emissions was fossil fuel combustion (93%), with minor emissions from deforestation (6%), aluminum production (<1%), cement production (<1%), and lime production (<1%). Contributors to CH_4 emissions were landfills (47%), domesticated animals (38%), manure management (9%), natural gas production (6%), and burning of agricultural waste (<1%). Nitrous oxide emissions were accounted for by fertilizer use, and perfluorocarbon emissions were accounted for by aluminum production.	PM-10 (5) CO (1)
Pennsylvania	Humid Continental (Hot Summer)	The majority of Pennsylvania's emissions came from CO_2, with the burning of fossil fuels constituting most of the CO_2 emissions in both years. The largest end-use categories for fossil fuel combustion were electricity production, transportation, and industrial uses. CH_4 was the next largest contributor, mostly from coal mining, oil, and natural gas systems, and the anaerobic decay of solid waste in landfills. N_2O came chiefly from manure management and the burning of fossil fuels. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) were emitted from a number of industrial processes. The doubling of HFC/PFC/SF6 emissions in 1999 was largely a result of the replacement of ozone-depleting substances (CFCs) with HFCs, which have high global warming potentials.	PM-2.5 (8) SO_2 (2) 8-Hour O_3 (17)
Rhode Island	Humid Continental (Hot Summer)	The only reported source of CO_2 emissions was fossil fuel combustion. Sources of CH_4 emissions were landfills (80%), wastewater treatment (7%), domesticated animals (6%), fossil fuel combustion (6%), and manure management (1%). N_2O emissions were primarily attributable to fossil fuel combustion (92%), wastewater treatment (6%), and agricultural soils (2%).	8-Hour O_3 (1)
South Carolina	Humid Subtropical	N/A	8-Hour O_3 (3)
South Dakota	Humid Continental (Warm Summer)	N/A	None
Tennessee	Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (97%), the majority of which is utility coal. CO_2 sinks (i.e., an increase in forest carbon storage) offset about 4% of the total CO_2 emissions. Sources of CH_4 emissions were landfills (51%), domesticated animals (27%), coal mining and natural gas production (11%) and manure management (10%). N_2O emissions were attributable to fertilizer use and agricultural crop wastes.	PM-2.5 (2) 8-Hour O_3 (6)
Texas	Semiarid/ Desert/ Humid Subtropical	The majority of CO_2 emissions were from fossil fuel combustion (96%), with the remainder due to land-use change and forestry (3%) and cement manufacture (1%). Sources of CH_4 emissions were landfills (36%), domesticated animals (31%), oil and gas systems (26%), manure management (5%), rice cultivation (2%), and coal mining (<1%). N_2O emissions were attributable to acid production (51%), agricultural soil management (45%), and manure management (4%).	PM-10 (1) CO (1) 8-Hour O_3 (4)

States	Climate Type	Major Sources of Greenhouse Gas	Types and Number of Nonattainment Areas
Utah	Semiarid/ Desert	The major source of CO_2 emissions was fossil fuel combustion (97%), with minor emissions from cement and lime production and limestone use. Sources of CH_4 emissions were coal mining (51%), domesticated animals (21%), natural gas/oil extraction (15%), and landfills (13%). N_2O emissions were attributable to nitric acid production (72%) and fertilizer use (28%).	PM-10 (3) SO_2 (2)
Vermont	Humid Continental (Warm Summer)	The only source of carbon dioxide emissions was fossil fuel combustion, the majority of which is due to transportation petroleum. Carbon dioxide sinks (i.e., an increase in forest carbon storage) offset about 1.3% of the total carbon dioxide emissions. Sources of methane emissions were domesticated animals (65%), landfills (33%) and manure management (1.3%). Nitrous oxide emissions were attributable to fertilizer use.	None
Virginia	Humid Continental (Hot Summer)/ Humid Subtropical	The major source of CO_2 emissions was fossil fuel combustion (99%). CO_2 sinks (i.e., an increase in forest carbon storage) offset about 16% of the total CO_2 emissions. Contributors to CH_4 emissions were landfills (70%), coal mining (21%), manure management (5%), and domesticated animals (4%). Nearly all N_2O emissions were accounted for by fertilizer use (93%), with minor emissions from agricultural burning.	8-Hour O_3 (5) PM-10 (1)
Washington	Marine West Coast/Semiarid	The major source of CO_2 emissions was fossil fuel combustion (99%), with minor emissions from lime manufacture, aluminum production, and cement production. Carbon dioxide sinks (i.e., increases in forest carbon stocks) offset about 25% of the total CO_2 emissions. Contributors to CH_4 emissions were landfills (66%), domesticated animals (19%), manure management (11%), coal mining (2%), and burning of agricultural waste (1%). Nitrous oxide emissions were accounted for by fertilizer use (97%), and the burning of agricultural waste (3%). All perfluorocarbons were emitted from aluminum production.	None
West Virginia	Humid Continental (Hot Summer)	CO_2 accounted for the majority of West Virginia's emissions. These emissions were mostly due to the burning of fossil fuels, primarily for the production of electricity. CH_4 was the next largest contributor, mostly from coal mining. N_2O, the third largest contributor, came chiefly from agricultural soil management and fossil fuel combustion. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), all of which resulted from industrial processes, each made up a small share of the total emissions as well.	PM-2.5 (5) PM-10 (2) SO_2 (1) 8-Hour O_3 (6)
Wisconsin	Humid Continental (Warm Summer/Hot Summer)	The major source of CO_2 emissions was fossil fuel combustion (99%). CO_2 sinks resulting from land use were not estimated in this inventory. Contributors to CH_4 emissions were domesticated animals (55%), landfills (22%), coal mining (8%), natural gas production (9%), manure management (6%), and fossil fuel combustion (1%). N_2O emissions were attributable to agricultural soils (63%), fossil fuel combustion (35%), and waste combustion (2%).	8-Hour O_3 (5)
Wyoming	Semiarid/ Unclassified Mountainous	N/A	PM-10 (1)

Note: (1) Sources reported by the most recently published State GHG Emissions and Sinks Inventory summaries.

NA = Not Available

Source: Encarta, 2005d; EPA, 2005a; EPA, 2006a.

3.3 GEOLOGIC RESOURCES

The following section describes geologic resources on a nationwide basis that may be affected by sequestration projects, including potential CO_2 capture and storage field validation projects and activities associated with MM&V and research efforts.

3.3.1 Definition of Geologic Resources

Within a given physiographic province, geologic resources typically are described by the geology, soils, groundwater, geologic hazards, and mineral resources of the area, as defined below.

- Geology - The rock types and structures that form the Earth's crust.
- Soils - Unconsolidated materials above the bedrock.
- Groundwater - Water in the zone of saturation below the water table.
- Geologic hazards - A geologic condition or phenomenon that presents a risk or is a potential danger to life and property, either naturally occurring (e.g., earthquakes, volcanic eruptions) or man-made (e.g., ground subsidence).
- Mineral Resources - The presence, distribution, quantity, and quality of mineral resources that are of economic value (e.g., oil, natural gas, coal, and others).

3.3.2 Overview of Geologic Resources in the U.S.

3.3.2.1 Geology Overview

Although the science of geology involves the study of many components that comprise the Earth, from plate tectonics to mineral composition, this discussion will use the term geology to refer to the rock types that are present in a particular area. There are three rock types that comprise the rock cycle, igneous, sedimentary, and metamorphic, as described below.

- Igneous rocks are formed by the solidification and crystallization of cooling magma (i.e., molten rock material). Magmas form at depth below the ground surface and the molten material may or may not reach the surface of the Earth before it cools and solidifies. Examples of igneous rocks include granite (cooled slowly while still buried below the surface) and basalt (magma that reaches the surface before cooling). All igneous rocks are crystalline in some form and generally there is little pore space that can be occupied by fluids, including water. Most igneous rocks are structurally strong until fractured or weathered.

- Sedimentary rocks are formed when sediments (loose, unconsolidated mineral or rock particles that have been transported by wind, water, or ice, and re-deposited) are compacted or cemented together into a solid rock. Sedimentary rocks are formed at or near the Earth's surface and are generally more compact than the original sediments. Types of sedimentary rocks include sandstone (cemented sand-sized particles), shale (compacted very fine-grained materials), and limestone (formed by precipitation from solution, composed mostly of calcite). Generally, fluids can travel through sedimentary rocks at varying rates depending on the degree of cementation and the material that makes up the sedimentary rock. For example, moderately cemented sandstone can transmit water (aquifer) while an intact shale unit will prohibit the flow of water (aquitard). Many sedimentary rocks are not structurally strong unless the rock exhibits extensive cementation.

- Metamorphic rocks are formed from other, preexisting rocks that are subjected to very high temperatures and/or pressures. High temperatures can cause re-crystallization or the development of new minerals, and pressure can deform the rock. These changes occur while the rock is still solid. Any type of preexisting rock can be metamorphosed, and examples include marble (metamorphosed limestone), quartzite (metamorphosed quartz-rich sandstone), and slate (metamorphosed shale that develops foliation under the applied stress). The ability of a metamorphic rock to transmit a fluid and the strength of the rock are dependent on the origin of the both the preexisting rock and the stress applied. Generally, a metamorphic rock behaves similarly to an igneous rock.

The U.S. can be subdivided into distinct geomorphic provinces that share a common geologic character and history (Section 3.3.3). These provinces are important since many geologic formations could serve as potential sinks, or places where carbon can be placed and prevented from reaching the atmosphere. When CO_2 is sequestered in a geologic formation, the mineral resources in and adjacent to the formation would no longer be available to be extracted.

3.3.2.2 Soils Overview

Soils are dynamic ecosystems composed of a combination of minerals, organic matter, and living organisms. The variety of soil types is the result of the diversity of minerals and organisms that compose them. Soils consist of four main types: sand, silt, clay, and loam. Sandy soils have a coarse texture; clay soils have a sticky texture; and silt particles, which are smaller than sand particles but larger than clay, give soils a silky, powdery texture. Loam soils, which are the best for agriculture, consist of sand, silt, and clay. Mineral and organic particles make up about 50 percent of soil volume; pores containing air and water make up most of the remaining volume.

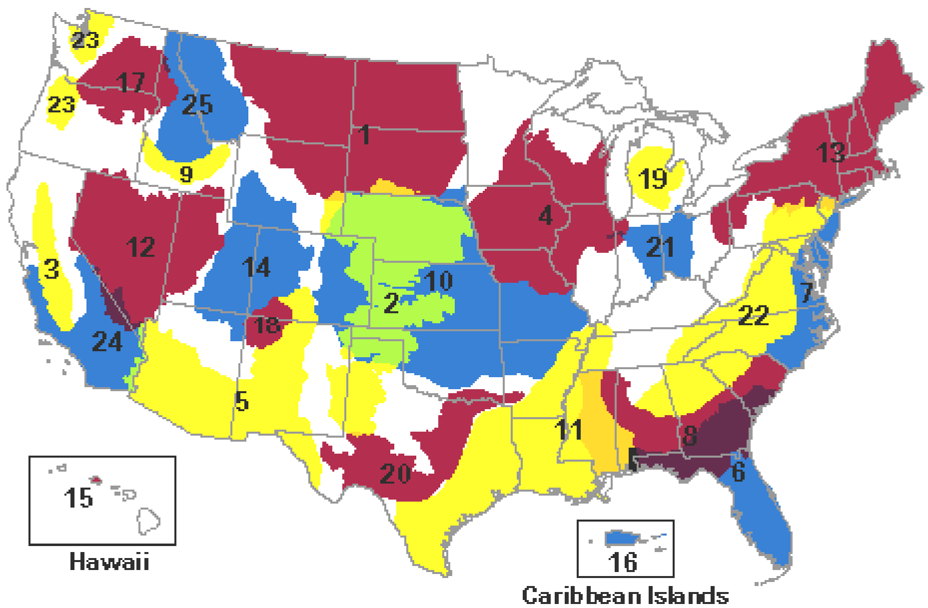
Soils form continuously, but very slowly, through the weathering of rocks by wind and rain. In addition to minerals from the weathering of rocks, soils contain organic matter, called humus, from the decomposition of plants and animals. As soils form over time, layers build up, called horizons, which have different characteristics and composition.

3.3.2.3 Groundwater Overview

Groundwater is part of the hydrologic cycle that lies beneath the water table. Groundwater aquifers, or porous subterranean regions saturated with groundwater, underlie most of the land in the U.S. Large volumes of usable groundwater exist within these aquifers. Figure 3-10 depicts some of the major regional aquifer systems in the U.S. For example, the High Plains aquifer (also called the Ogallala Aquifer) underlying the midwestern U.S. is thought to contain almost a quadrillion gallons of water (Figure 3-11). Approximately 50 percent of the population in the U.S. derives a portion of its freshwater from groundwater sources, and more than a third of the water used in agriculture practices is obtained from groundwater aquifers.

Carbon sequestration activities are focused on storage in deep saline formations. (Discussed in 3.3.5.3).When CO_2 is injected into a formation, there is a potential for the CO_2 gas to escape into shallower formations, cause contamination of usable groundwater, or create other adverse effects. It is possible to minimize these potential adverse impacts through careful site selection, detailed hydrogeologic characterization, and subsurface hydraulic testing to verify the subsurface reservoir is favorable for long-term isolation of the fluids. Understanding the site-specific geologic conditions and limitations are important to ensure that only suitable locations for geologic sequestration are proposed. Moreover, it is crucial to comply with relevant UIC regulations and to employ BMPs for injection well construction, operation and monitoring. Potential impacts to geologic resources are further described in Chapter 4.

Between 1950 and 1995, annual groundwater withdrawal increased 150 percent in the U.S. Some aquifers are recharged regularly by rainfall or from surface water sources; however, the current rate of groundwater extraction exceeds long-term recharge rates in many basins (USGS, 2000b). Depletion of groundwater in storage increases the costs of extraction and may induce water quality degradation, land subsidence, and eventually loss of the resource. Several areas in the U.S. currently experiencing significant groundwater depletions include parts of the west and midwest, the lower Mississippi Valley, sections of the southeast including Florida, the Chicago-Milwaukee area, and eastern Washington. Additionally, groundwater mining is a growing concern for the High Plains Aquifer that underlies parts of Colorado, Kansas, Oklahoma, Nebraska, New Mexico, South Dakota, Texas and Wyoming where groundwater withdrawals account for 96 percent of all groundwater withdrawals nationally (Levin et al., 2002; USGS, 1999).



Regional Aquifer Systems in the United States	
1 Northern Great Plains	14 Upper Colorado River basin
2 High Plains	15 Oahu, Hawaii
3 Central Valley, California	16 Caribbean Islands
4 Northern Midwest	17 Columbia Plateau
5 Southwest Alluvial Basins	18 San Juan Basin
6 Floridian	19 Michigan Basin
7 Northern Atlantic Coastal Plain	20 Edwards-Trinity
8 Southeastern Coastal Plain	21 Midwestern Basins and Arches
9 Snake River Plain	22 Appalachian Valleys and Piedmont
10 Central Midwest	23 Puget-Willamette Lowland
11 Gulf Coastal Plains	24 Southern California Alluvial Basins
12 Great Basin	25 Northern Rocky Mountain Intermontane
13 Northeast Glacial Aquifers	

Note: This map is from one USGS study and does not represent all regional aquifers in the U.S.

Source: USGS, 2000b.

Figure 3-10. Regional Aquifer Systems in the United States

Groundwater protection occurs at the Federal, State, and local government levels through various agencies. Environmental, agricultural, and natural resource agencies regulate groundwater extraction and preservation through laws, regulations, and policies. The EPA has designated approximately 75 sole source aquifers nationwide. This designation is intended to protect drinking water supplies in areas with few or no alternative water resources. The EPA must review any project within a sole source aquifer designated area that will be receiving federal financial assistance. A summary of the sole source aquifers in the U.S. is provided in Table 3-4 (EPA, 2005).

Table 3-4. Sole Source Aquifers in the United States

EPA Region	Sole Source Aquifer Name	State(s)
I	Pootatuck Aquifer	CT
	Cape Cod Aquifer	MA
	Nantucket Island Aquifer	
	Martha's Vineyard Aquifer	
	Head of Neponset Aquifer System	
	Plymouth-Carver Aquifer	
	Canoe River Aquifer	
	Broad Brook Basin of the Barnes	
	Monhegan Island	ME
	Vinalhaven Island Aquifer System	
	North Haven Island Aquifer System	
	Isleboro Island Aquifer System	
	Block Island Aquifer	RI
	Hunt-Annaquatucket Pettaquamscutt	
	Pawcatuck Basin Aquifer System	RI, CT
II	Buried Valley Aquifers, Central Basin, Essex and Morris Counties	NJ
	Upper Rockaway River Basin	
	Ridgewood Area Aquifers	
	Highlands Aquifer System- Passaic, Morris & Essex Cos. NJ; Orange Co. NY	NJ, NY
	NJ Fifteen Basin Aquifers	
	Ramapo River Basin Aquifer Systems	
	NJ Coastal Plain Aquifer System	NJ, DE, PA
	Nassau/Suffolk Co., Long Island	NY
	Kings/Queens Counties	
	Schenectady/Niskayuna	
	Clinton Street-Ballpark Valley Aquifer System, Broome and Tioga Cos.	
	Cattaraugus Creek Basin Aquifer, WY & Allegany Cos.	
	Cortland-Homer-Preble Aquifer System	
III	Maryland Piedmont Aquifer – Montgomery, Howard, Carroll Cos.	MD
	Poolesville Area Aquifer Extension of the Maryland Piedmont Aquifer	
	Seven Valleys Aquifer, York County	PA
	Prospect Hill Aquifer, Clark County	VA
	Columbia and Yorktown, Eastover Multi-aquifer System – Accomack, N. Hampton	
IV	Biscayne Aquifer, Broward, Dade, Monroe & Palm Beach Cos.	FL
	Volusia-Floridan Aquifer, Flagler & Putnam Cos.	
	Southern Hills Regional Aquifer System	LA/MS
V	St. Joseph Aquifer System	IN
	Mille Lacs Aquifer	MN
	Pleasant City Aquifer	OH
	Bass Island Aquifer, Catawba Island	
	Miami Valley Buried Aquifer	
	OKI extension of the Miami Buried Valley Aquifer	
	Allan County Area Combined Aquifer System	

EPA Region	Sole Source Aquifer Name	State(s)
VI	Chicot Aquifer System	LA
	Arbuckle-Simpson Aquifer, South Central Oklahoma	OK
	Edwards Aquifer, San Antonio Area	TX
	Edwards Aquifer, Austin Area	TX
VII	None	--
VIII	Missoula Valley Aquifer	MT
	Castle Valley Aquifer System	UT
	Western Unita Arch Paleozoic Aquifer System at Oakley, UT	
	Glen Canyon Aquifer System	
	Eastern Snake River Plain Aquifer Stream Flow Source Area	WY
	Elk Mountain Aquifer	
IX	Upper Santa Cruz & Avra Basin Aquifer	AZ
	Bisbee-Naco Aquifer	
	Fresno County Aquifer	CA
	Santa Margarita Aquifer, Scotts Valley	
	Campo/Cottonwood Creek	
	Ocotillo-Coyote Wells Aquifer	
	Northern Guam Aquifer System	GU
	Southern Oahu Basal Aquifer	HI
	Molokai Aquifer	
X	Eastern Snake River Plain Aquifer	ID, WY
	North Florence-Dunal Aquifer	OR
	Spokane Valley Rathdrum Prairie Aquifer	WA, ID
	Lewiston Basin Aquifer	
	Camano Island Aquifer	WA
	Whidbey Island Aquifer	
	Cross Valley Aquifer	
	Newberg Area Aquifer	
	Cedar Valley (Renton Aquifer)	
	Central Pierce Cty. Aquifer System	
	Marrowstone Island Aquifer System	
	Vashon-Maury Island Aquifer System	
	Guemes Island Aquifer System	

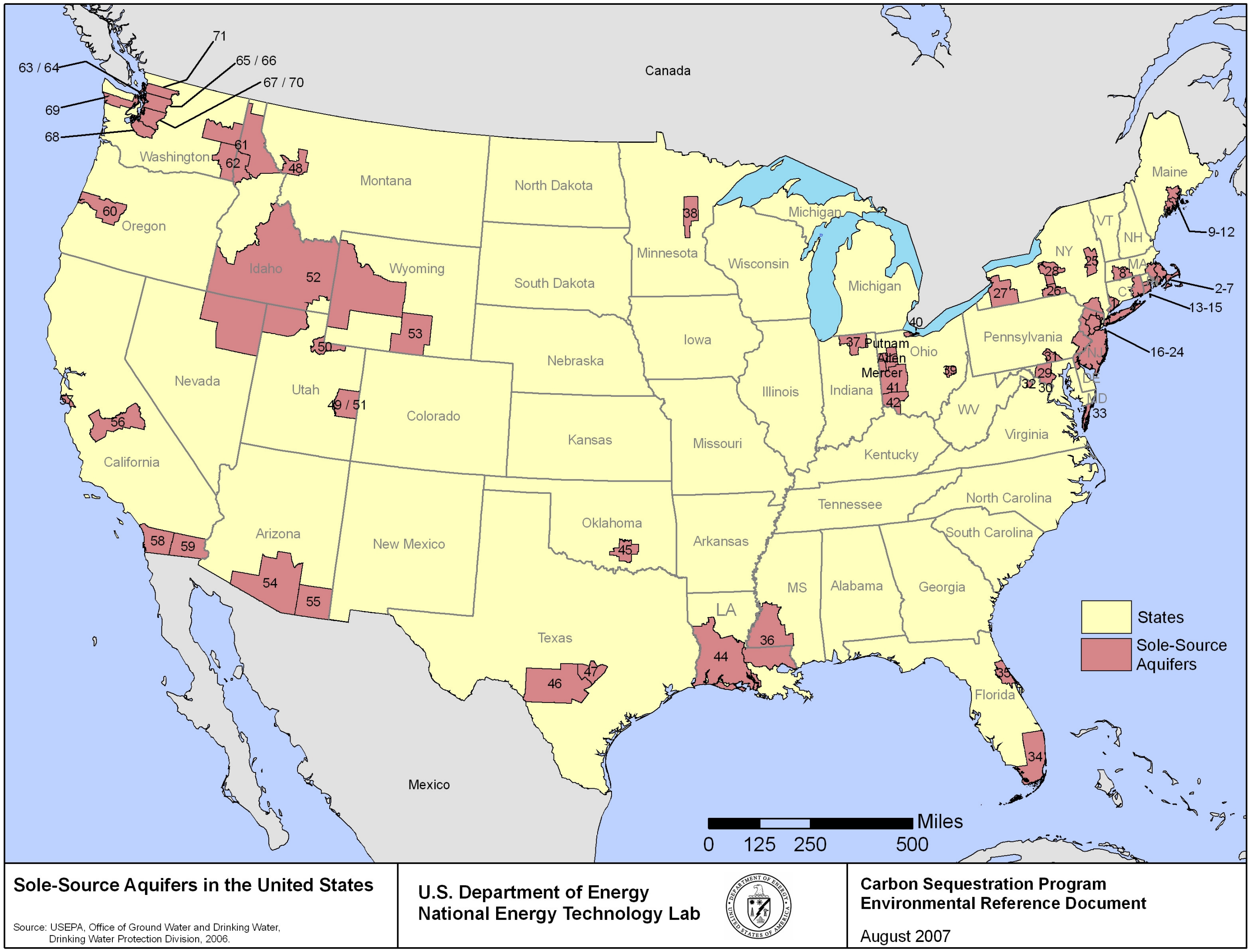


Figure 3-11. Sole-Source Aquifers in the U.S.

3.3.2.4 Hazards Overview

Geologic hazards could be caused, triggered or exacerbated by potential sequestration activities. Knowledge of the location of geologic hazards will therefore be integrated into the site selection process for future sequestration projects.

Geologic hazards are present in various forms (e.g., volcanoes, earthquakes, landslides, subsidence, etc.) throughout the U.S., and these hazards can potentially cause both harm to human health and safety and property damage. Although geologic hazards exist and can be exacerbated by human activities (e.g., deep injection wells), knowledge of the location of hazards will be integrated into the selection process for the location of future sequestration projects. By design, therefore, project locations will be selected to avoid areas of extreme hazards. This section discusses the geologic hazards that could be caused, triggered, or exacerbated by the potential sequestration activities.

An earthquake may be caused by deformation of rocks in the Earth's crust. Typically earthquakes are attributable to a sudden rupture of the rocks adjacent to a geologic structure, such as an active fault, due to excessive build up in the tectonic stress in that area. In addition to severe shaking of the ground surface, large earthquakes may cause other damaging effects to the environment, such as surface fracturing, landslides, liquefaction, tsunamis, and seiches. Some earthquakes appear to have been triggered in regions of elevated tectonic stress by anthropogenic activities such as deep well injection or filling of large surface reservoirs.

The areas of greatest seismic activity in the U.S. generally tend to be along the western rim of North America and where the boundaries of Missouri, Arkansas, Tennessee, Kentucky, and Illinois converge (USGS, 2005b). The latter is the New Madrid Seismic Zone (also known as the Reelfoot Rift or the New Madrid Fault Line). Between 1974 and 2003, Alaska had 12,053, or 57.2 percent, of all U.S. earthquakes. Alaska was followed by California (4,895, 23.2 percent), Hawaii (1,533, 7.3 percent), Nevada (778, 3.7 percent), Washington (424, 2.0 percent), Idaho (404, 1.9 percent), and Wyoming (217, 1.0 percent). Other top-15 earthquake states (with less than one percent of the U.S. earthquakes) are in descending order, Montana, Utah, Oregon, New Mexico, Arkansas, Arizona, Colorado, and Tennessee. Figure 3-12 depicts seismic hazard areas in terms of peak acceleration and probability.

Landslides are widespread in areas of steep topography with high relief. Annually, landslides cause approximately $2 billion in damages and an average of more than 25 fatalities. Landslides occur in all 50 states and are common throughout the Appalachian and New England Regions, but also occur across the Interior Plains and into the mountain areas of the western U.S.

Land subsidence is a gradual settling or sudden sinking of the ground surface. In the U.S., more than 17,000 square miles in 45 states have been directly affected by subsidence. The principal causes for subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydro-compaction, natural compaction, sinkholes, and thawing permafrost.

Geologic hazards can become more likely when some types of projects are conducted. For example, when gases or liquid are injected into the subsurface via injection wells, there is a potential for increased seismic activity or earthquakes, depending on the geologic conditions. Therefore, it will be important to review the potential for geologic hazards at the future site of any sequestration project in order to avoid adverse impacts to other resources that may be caused if the sequestration process (including long-term storage) triggers or exacerbates natural geologic hazards at the site.

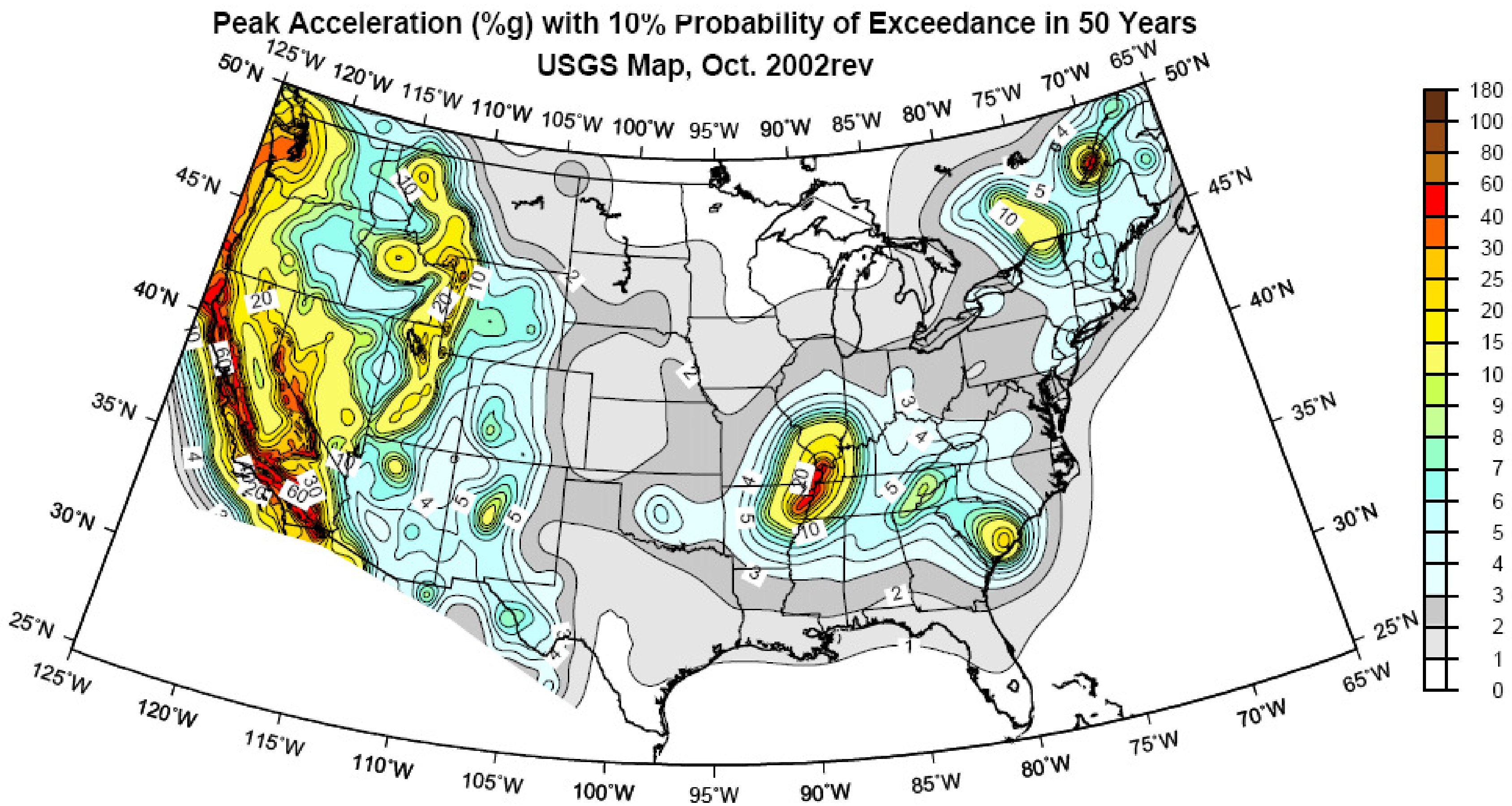
3.3.2.5 Mineral Resources Overview

Various mineral resources can be found throughout the U.S., including coal deposits, oil and gas reservoirs, and other mineral deposits. As several of the proposed geologic sequestration technologies are directly related the distribution of coal seams and oil and gas reservoirs, these mineral resources are discussed below.

Approximately 1,071 million short tons of coal are produced from the regions shown in Figure 3-13 The coal in these regions varies in rank from anthracite to sub-bituminous as shown in Figure 3-14 and Figure 3-15.

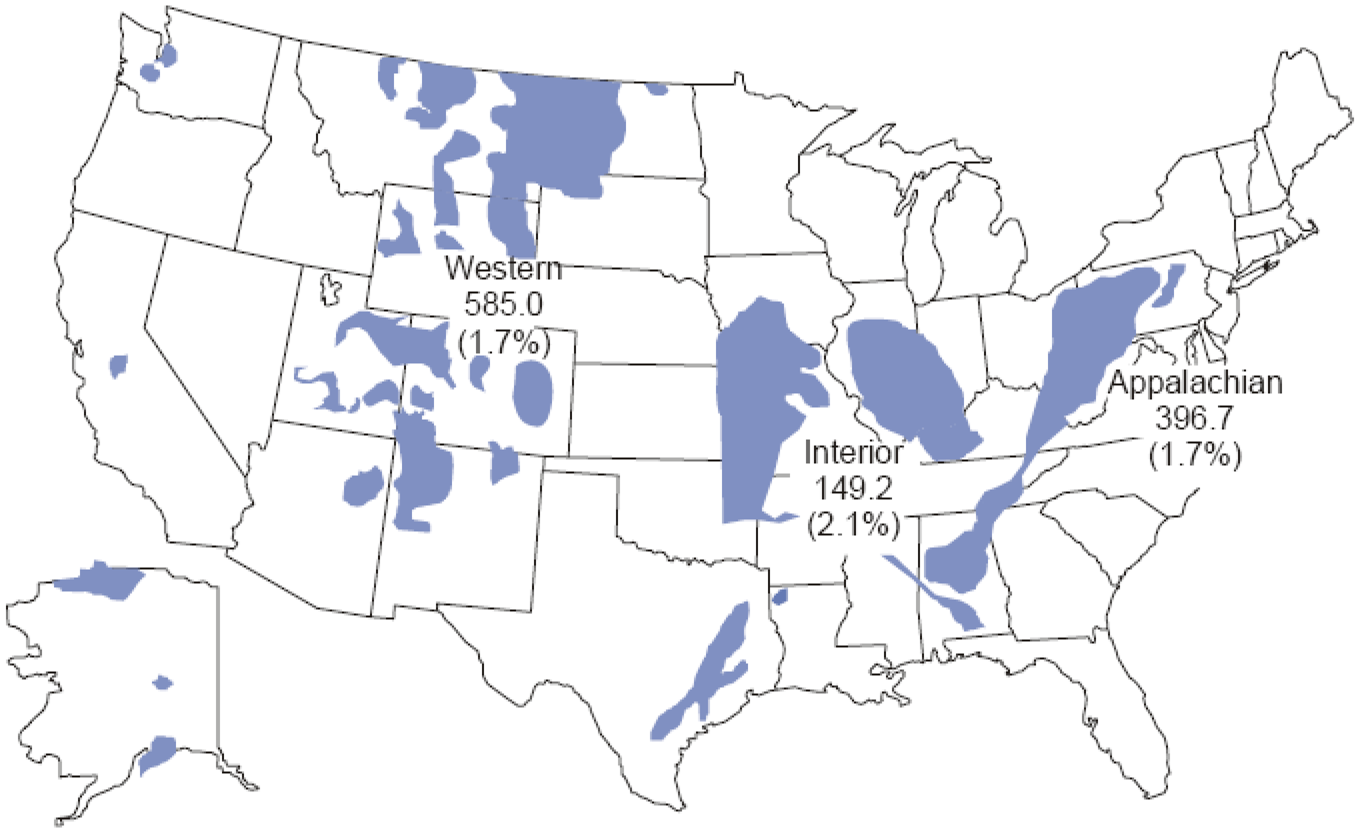
According to the EIA, there were 21,891 million barrels of crude oil proved reserves as of December 31, 2003 (EIA, 2005a). The majority of crude oil discoveries in 2003 were new fields in the Gulf of Mexico Federal Offshore reserves. Since 1977, crude oil reserves have been primarily sustained by expansion of the proven reserves in existing fields rather than the discovery of new oil fields. Oil and gas basins of the U.S. are shown in Figure 3-16 and Figure 3-17 (USGS, 2005a). Oil and gas resources in the U.S. are shown in Figure 3-18 and Figure 3-19.

As of December 31, 2003, the EIA also indicated there were 189,044 billion cubic feet of dry gas reserves in the U.S (EIA, 2005b). Production declines in the Gulf of Mexico, New Mexico, and Louisiana were offset by production increases in Colorado, Texas, Oklahoma, and Wyoming. Coal-bed methane proved reserves were 18,743 billion cubic feet in 2003, accounting for 10 percent of U.S. dry gas proved reserves. The potential for future development of CBM resources is indicated in Figure 3-20. Alaska has the highest predicted CBM future resources, followed by the Powder River Basin in Wyoming and Montana, the Northern Appalachian Basin in West Virginia, Ohio, and Pennsylvania, and the San Juan Basin in Colorado and New Mexico (USGS, 2005a).



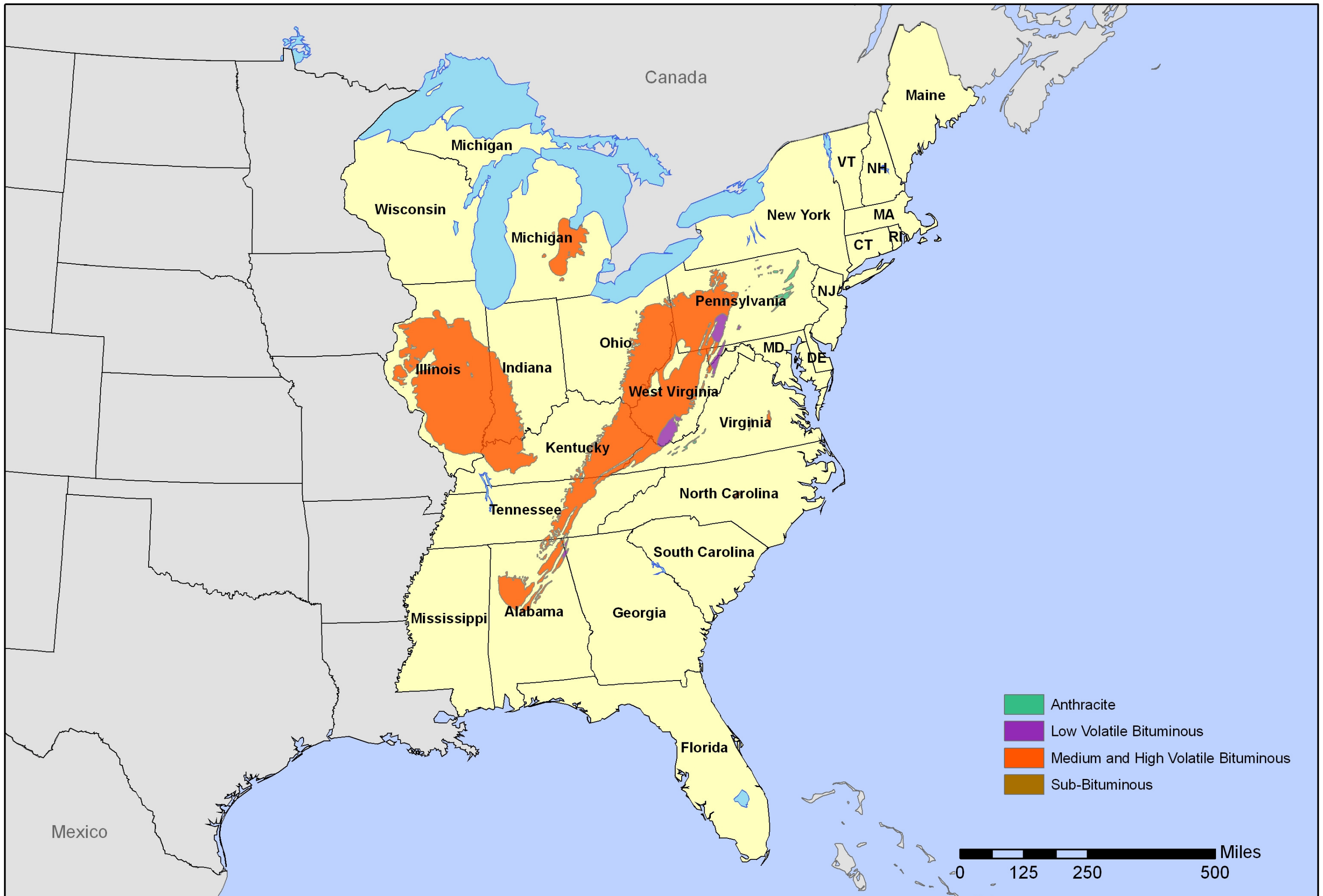
Source: USGS, 2003.

Figure 3-12. Seismic Hazard Map of the U.S.



Source: EIA, 2005c.

Figure 3-13. Coal Production in the U.S. in 2005



Coal Types in the Eastern United States

Source: USGS; Eastern Energy Team; John Tully (comp.), 200108, Coal Fields of the United States; U.S. Geological Survey, Reston, VA.

U.S. Department of Energy
National Energy Technology Lab

Carbon Sequestration Program
Environmental Reference Document
August 2007

Figure 3-14. Coal Types - East

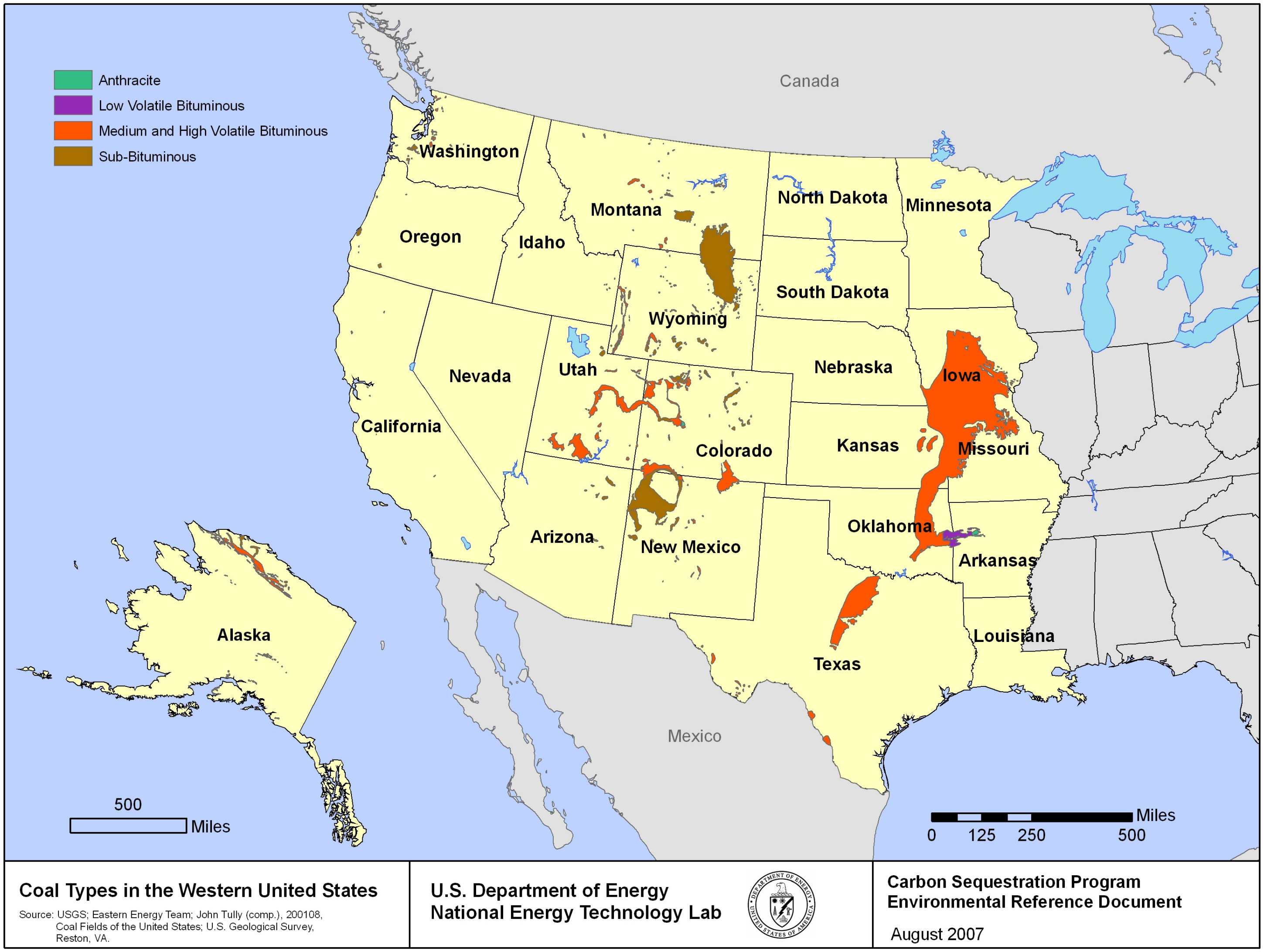


Figure 3-15. Coal Types - West

Oil and Gas Basins in the Eastern United States Source: USGS, USGS Central Energy Team, 1996.	**U.S. Department of Energy National Energy Technology Lab**	**Carbon Sequestration Program Environmental Reference Document** August 2007

Figure 3-16. Oil and Gas Basins - East

Figure 3-17. Oil and Gas Basins - West

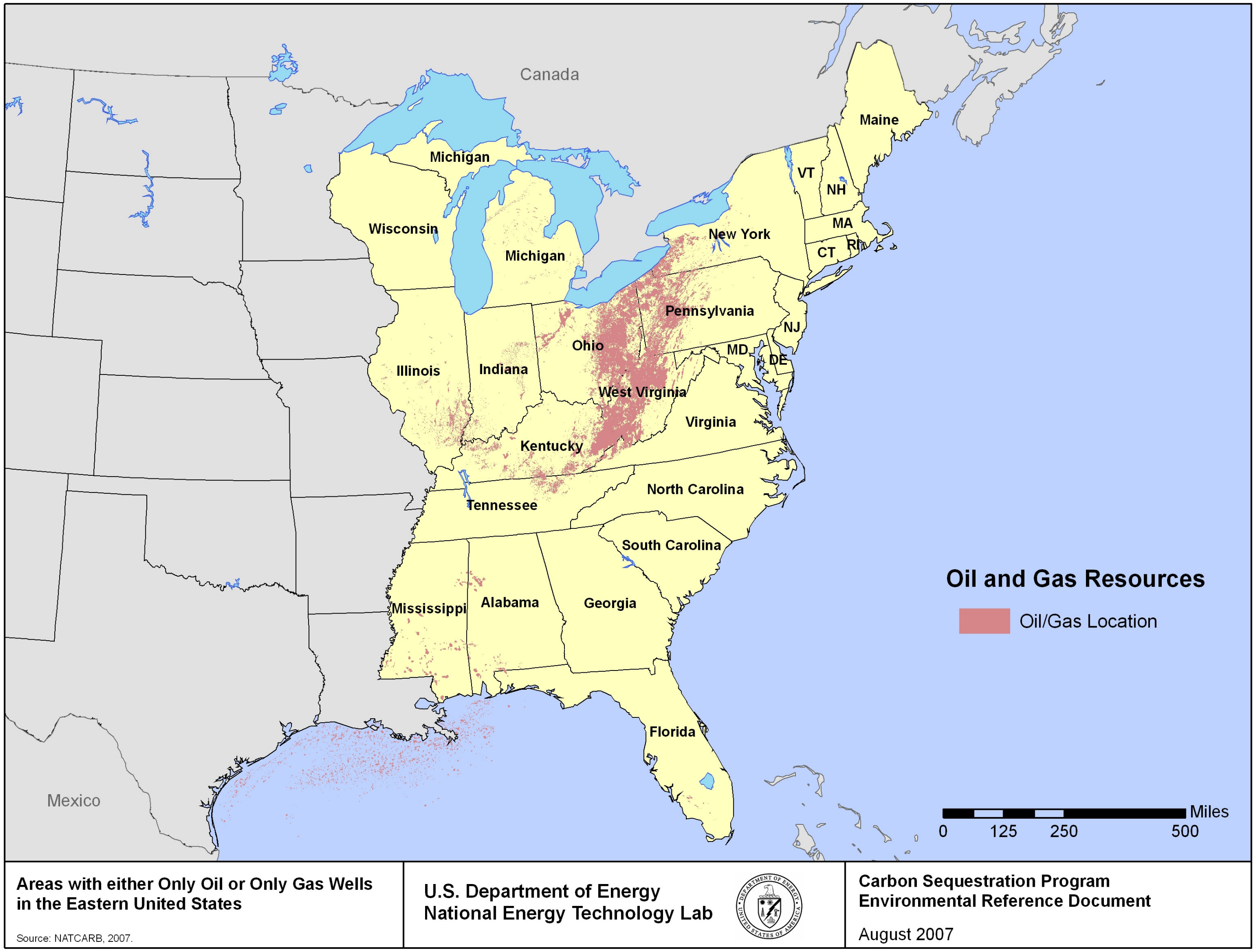


Figure 3-18. Oil and Gas Wells - East

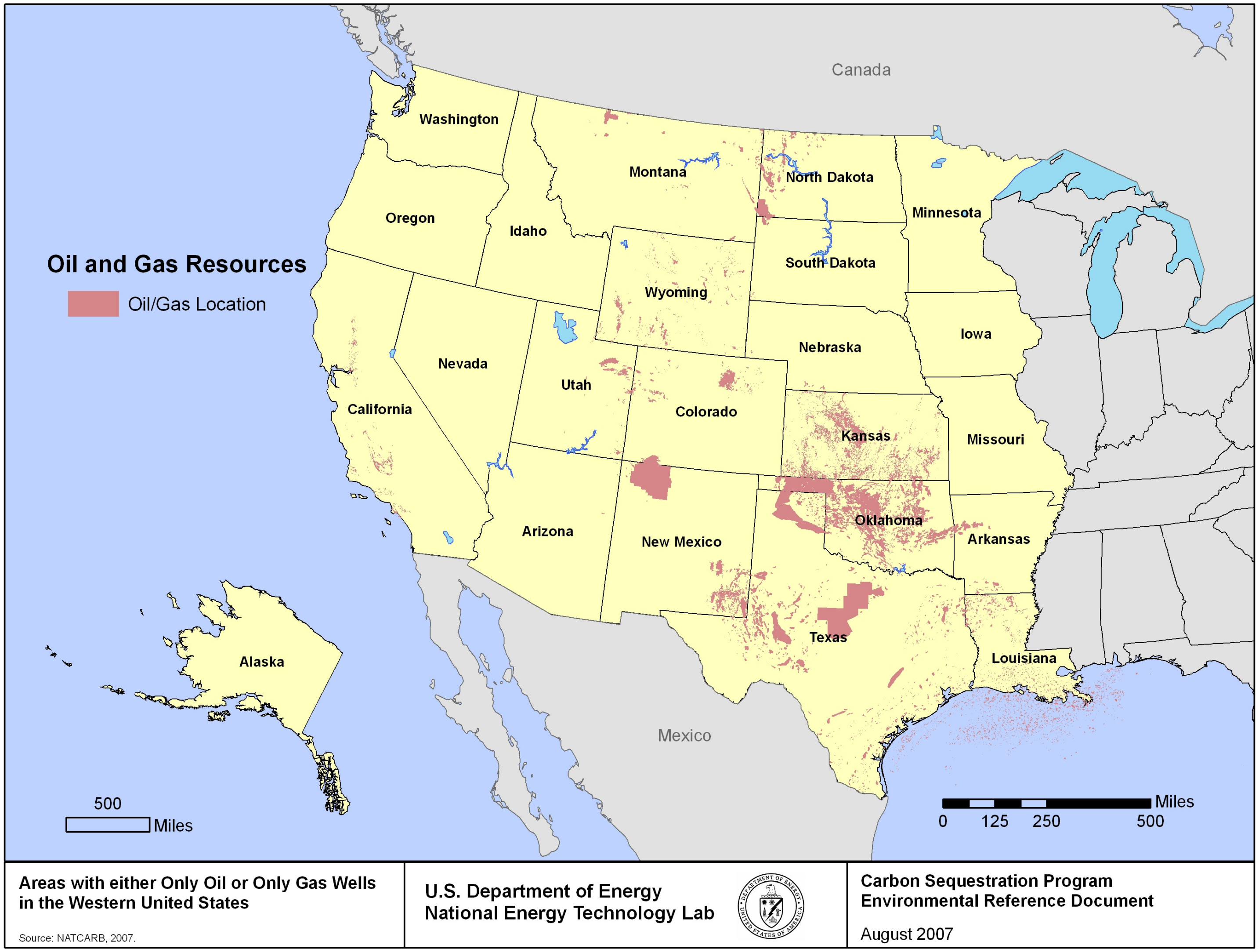


Figure 3-19. Oil and Gas Wells - West

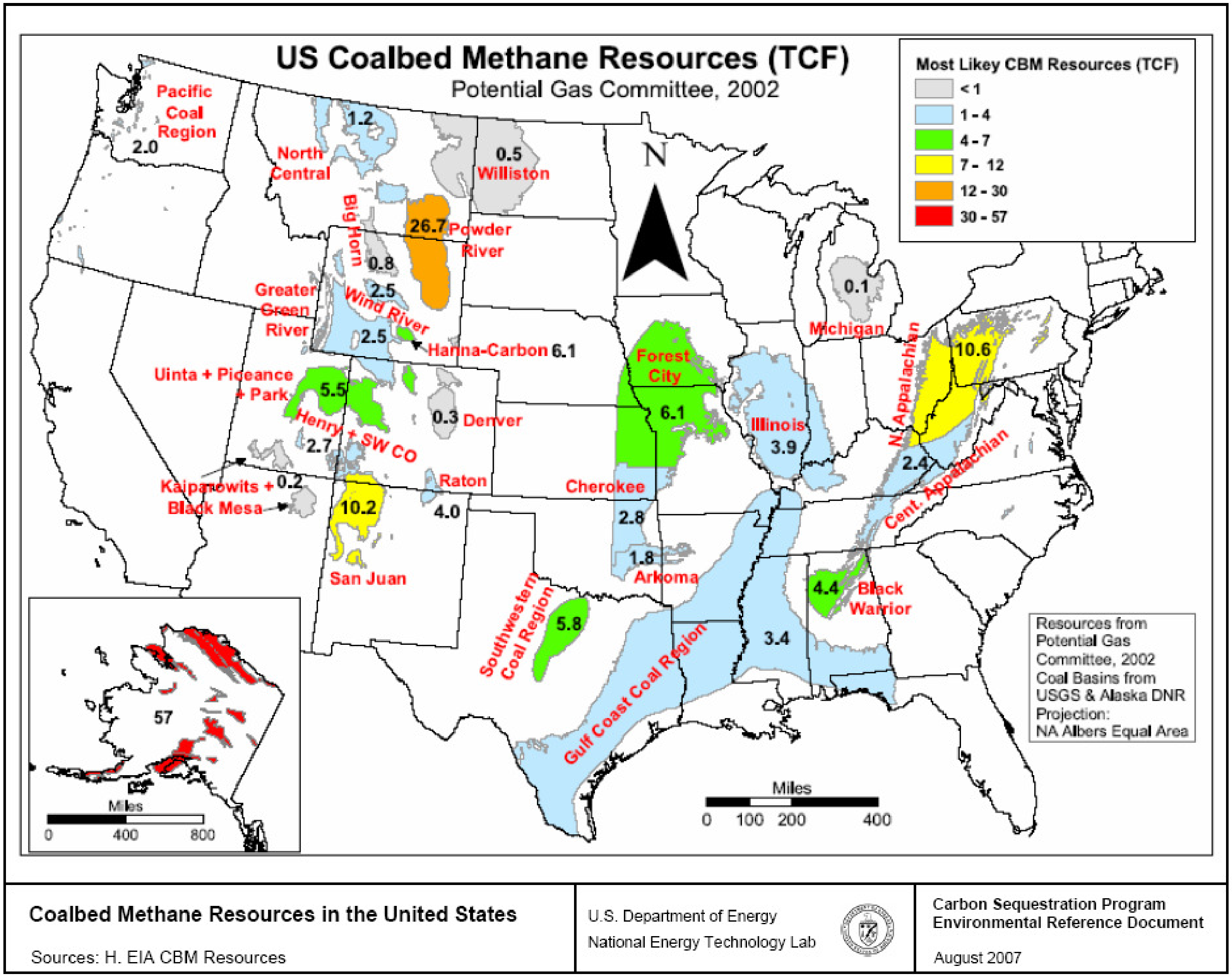


Figure 3-20. Coal Bed Methane

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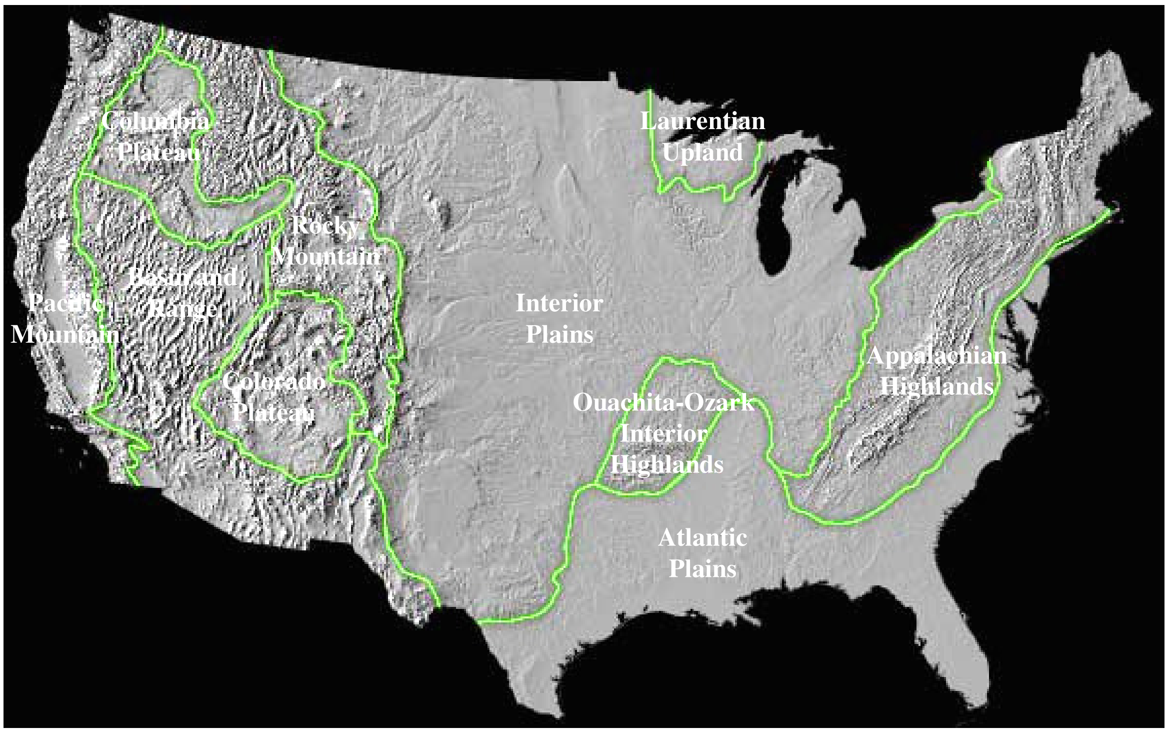
3.3.3 Geologic Provinces

As mentioned in the national overview of geology (Section 3.3.2.1), the U.S. can be subdivided into distinct geologic provinces having similar physiographic features and geologic characteristics. While as many as 25 geologic provinces have been recognized in the lower 48 states, the major divisions illustrated on Figure 3-22 are used to provide a summary description of the geologic features (USGS, 2000a).



Source: USGS, 2000a.

Figure 3-21. Geologic Provinces of the United States

3.3.3.1 Appalachian Highlands Province

The Appalachian Highlands Province is characterized by the Appalachian Mountain Range, which reveals elongated belts of folded marine sedimentary rocks, volcanic rocks, and slivers of ancient ocean floor. The ridges of the mountains are erosion-resistant sandstone, while the valleys are comprised of limestone and other less-resistant rock layers. Some molten rock in the Appalachian Highlands cooled very slowly and formed coarse-grained veins called pegmatites, which have been the source of high-purity minerals (such as feldspar, quartz, and mica) and gemstones (such as emeralds and beryl). Other minerals that can be found in the Appalachian Highlands include coal, iron ore (hematite), zinc, marble and slate. The Appalachian Basin is one of the most important coal-producing regions in the U.S. and the world. Historic and recent production records show that about 34.5 billion short tons of coal have been produced in this region.

3.3.3.2 Laurentian Upland Province

The Laurentian Upland Province area is part of the nucleus of North America referred to as the Canadian Shield. The bedrock in this region is composed predominantly of Precambrian igneous and metamorphic rocks. Large portions of this area were overlain by Paleozoic sedimentary rocks that were subsequently eroded to expose underlying Precambrian rock units. Substantial copper deposits were discovered in the Precambrian rocks on the Keweenaw Peninsula of northern Michigan during the latter half of the last century.

3.3.3.3 Atlantic Plain Province

The Atlantic Plain Province is characterized by the flattest topography of the provinces. It stretches over 2,200 miles in length from Cape Cod to the Mexican border and southward another 1,000 miles to the Yucatan Peninsula. The Atlantic Plain slopes gently seaward from the inland highlands in a series of terraces. This gentle slope continues far into the Atlantic Ocean and Gulf of Mexico, forming the continental shelf. Historically, sediments eroded from the Appalachian Mountains and other inland highlands were carried east and southward by streams and gradually covered the land, burying it under thousands of feet of layered sedimentary and volcanic debris. Today, the sedimentary rock layers that lie beneath much of the coastal plain and fringing continental shelf remain nearly horizontal. Mineral resources found in the Atlantic Plain Province include petroleum and natural gas, phosphate, uranium, salt, sulfur, heavy minerals sands, and clays.

3.3.3.4 Ouachita-Ozark Interior Highlands Province

The ancient, eroded mountains of the Ouachita-Ozark Highlands stand surrounded by the nearly flat-lying sedimentary rocks and deposits of the Interior and Atlantic Plains Provinces. In the Ouachita Mountains, folds and faults now contort these ancient marine rocks. The rocks closely match deformed strata found today in the Marathon Mountains of Texas and the southern Appalachians. Mineral resources produced in the province include limestone, quartzite, sand and gravel, asphaltite, lead, and oil and gas.

3.3.3.5 Interior Plains Province

The Interior Plains Province is a vast region that spreads across the craton of North America. Precambrian metamorphic and igneous rocks now form the basement of the Interior Plains and are the stable nucleus of North America. With the exception of the Black Hills of South Dakota, the entire region has low relief, reflecting more than 500 million years of relative tectonic stability. Sediments eroding from the rising Rocky Mountains to the west washed into the ancient Sundance Sea and were deposited as layered wedges of fine debris. Preserved within the multi-hued sandstones, mudstones, and clays that made up the shoreline are the remains of countless dinosaurs that roamed the Sundance coast.

3.3.3.6 Rocky Mountain Province

The Rocky Mountain Province took shape during a period of intense plate tectonic activity that formed much of the rugged landscape of the western U.S. Deep basins that contain sediment shed from the mountains by erosion separate individual mountain ranges. These basins are often the source of oil and gas deposits.

3.3.3.7 Colorado Plateau Province

The Colorado Plateau Province encompasses a vast region of plateaus, mesas, and deep canyons and is characterized by nearly horizontal layers of sedimentary rock that have been deeply dissected by stream erosion, especially by the Colorado River. Thick layers of limestone, sandstone, siltstone, and shale were laid down in the shallow marine waters. One of the most geologically intriguing features of the Colorado

Plateau is its remarkable stability. Relatively little rock deformation (faulting and folding) has affected this high, thick crustal block within the last 600 million years or so. In contrast, provinces that have suffered severe deformation surround the plateau.

3.3.3.8 Basin and Range Province

The Basin and Range Province is characterized by a multitude of down-dropped valleys and elongated mountains. Basins filled with geologically young sedimentary rocks separate the ranges. Basalt flows also exist in some of these basins. Except for its relatively large amount of structural deformation and tectonic activity, this province is generally similar in geology to the Colorado Plateau Province.

3.3.3.9 Pacific Mountain Province

The Pacific Mountain Province is one of the most geologically young and tectonically active provinces in North America, and the landscape of this province provides evidence of ongoing mountain building. The Sierra Nevada mountain range is composed of mostly granitic rocks while the Cascade mountain range is made up of a band of thousands of very small, short-lived volcanoes.

3.3.3.10 Columbia Plateau Province

The Columbia Plateau Province includes one of the world's largest accumulations of lava. Over 170,000 cubic kilometers of basaltic lava, known as the Columbia River basalts, covers the western part of the province.

3.3.3.11 Pacific Mountain Province

In relation to the rest of the geology of North America, the Pacific Mountain Province is one of the youngest and most tectonically active provinces. The landscape of the province shows evidence of continuing mountain formation. The Sierra Nevada mountain range is composed of mostly granitic rocks while the Cascade mountain range is made up of a band of thousands of very small, short-lived volcanoes.

3.3.4 Summary of Geologic Resources Potentially Affected by Carbon Sequestration Technologies

There are three main components to the sequestration projects described in this section, capture of CO_2, geologic sequestration of CO_2, and MM&V of the project site before, during, and after sequestration. Each of these components has the potential to affect the geologic resources of the project area, and these effects are discussed in a general manner in the following text. A more detailed discussion for the various geologic sequestration technologies is included in Section 3.3.5 (CAN Europe, 2003a; Espie, 2004; Geotimes, 2003; NETL, 2005).

3.3.4.1 Post-Combustion Capture

The geologic resources affected by the capture of CO_2 are mainly limited to the capture location (e.g., at the power plants, oil refineries, or industrial sites) (CAN Europe, 2003b). The facilities that are constructed, the associated industrial processes, and the resulting potential for environmental releases could affect the geologic resources of an area; however, these effects would be site-specific, directly associated with the capture technology utilized, and dependent on the industrial CO_2 source.

Although the geologic resources of an area will need to be addressed on a site-by-site basis in future environmental documents, a few generalizations can be made for the potential effects of CO_2 capture on the geology, soils, and groundwater of a project area, including the following:

- Construction of CO_2 capture facilities could disturb the soils of an area.
- Any release or spill of materials involved in the capture of the CO_2 could affect the natural geology, soils, and groundwater quality.
- The capture of CO_2 may increase water consumption.
- An increase in water consumption for the capture process could also cause a proportional increase in the amount of wastewater that requires treatment or disposal.

3.3.4.2 Geologic Sequestration

Various geologic formations could be utilized to sequester the captured CO_2, including depleted oil reservoirs, unmineable coal seams, saline formations, and other formations as determined on a site-specific basis (Figure 1-10). The geologic resources of an area affected by geologic CO_2 sequestration technologies would be associated with the construction and operation of facilities, industrial processes, potential for environmental releases of materials, wastes, or chemicals, and reaction of the geologic formation to the addition of CO_2. Geologic resources that may be affected by applying these technologies include the following.

3.3.4.2.1 Geology

- The injection of CO_2 into a formation could potentially alter the natural geomorphology and activate a fault or fracture. In an extreme case the alteration might trigger a seismic event.
- The physical characteristics and current land use/resources located in an outcrop area of the geologic formation used for sequestration may be affected by leakage from sequestration activities. For example, if the formation outcrop is proximal to the injection location for sequestration in unmineable coal seams, CO_2 leakage may migrate up-dip in the coal seam or overlying formation and vent to the atmosphere where these outcrops daylight. Discharge of CO_2 from the outcrop may have adverse impacts to biological resources.
- The sequestration processes could cause undesirable migration of natural chemical constituents (e.g., heavy metals).

3.3.4.2.2 Soils

- The soils in the area of the sequestration site could be impacted if there is a spill or CO_2 leakage on site. The volume of soil impacted would depend on the size of the CO_2 plume and the migration pathway.
- The sequestration processes could stimulate the mobilization of heavy metals found in the soils.

3.3.4.2.3 Groundwater

- The natural water quality of the area could be impacted due to the sequestration processes.
- As a result of a sequestration project, potable water supplies could become contaminated due to several processes, which include migration of CO_2 after injection, leakage of formation fluids, or mobilization of chemical constituents (e.g., crude oil, CH_4 gas, metals, organic constituents, or brine water) from the host formation into overlying aquifers.
- The addition of CO_2 to a formation may decrease the natural pH of the formation water slightly. Co-sequestration of H_2S with the CO_2 may cause an even more substantial lowering of pH.

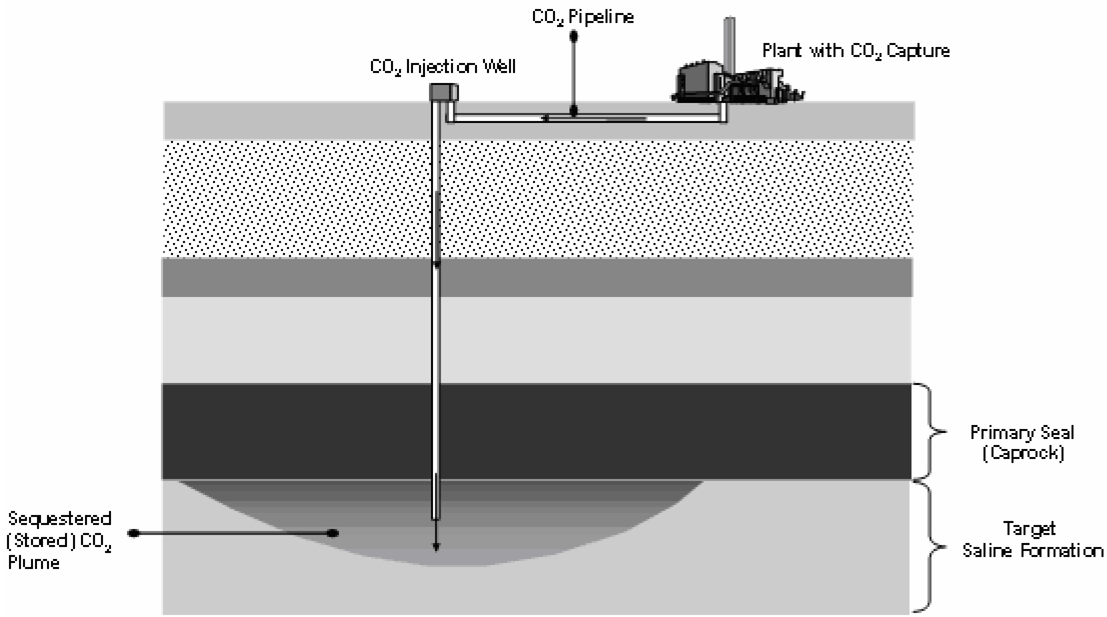


Figure 3-22. Geologic Formations and Sequestration

- Changes in formation pressure water pH could increase dissolved concentrations of natural elements present in the formation, and induce the dissolution of limestone formations, if present. Increasing the acidity of the formation water would also likely increase corrodibility and cause more rapid deterioration of well casings and equipment.
- The sequestration technologies could increase the need for water to use in operation and production processes. Additionally, there could be an increase in the amount of water that would need to be disposed of in a treatment or municipal system.

3.3.4.3 Monitoring, Mitigation, and Verification

The technologies associated with MM&V of CO_2 sequestration will vary based on the site, capture and sequestration processes utilized, and surrounding environment. MM&V will be utilized to verify the success of the capture technologies, determine the short- and long-term effectiveness of the sequestration operation, quantify any leak rates, and assess the influence of the technology on the surrounding environment. The geologic resources of an area may be affected by the facilities and equipment needed to implement MM&V efforts, including the use of chemicals, solvents, or dyes, and any wastes produced. Water resources, water quality, and the natural soil geochemistry may be affected by spills or leakage of these products. The use of geologic and groundwater models will help determine the success of the sequestration, as well as provide a basis for the refinement of processes.

Some of the MM&V technologies that can be utilized at a sequestration site include the following:

- Subsurface geophysics;
- High precision land surveying to detect changes in land surface due to the change in pressure at depth from the injection of CO_2 ;
- Fluid sampling (surface water, groundwater, etc.);

- Air sampling, especially near any potential leakage pathways like existing oil and gas production wells;
- Tracers to track the movement of the stored CO_2;
- CO_2 flux towers;
- Well pressure monitoring.

3.3.5 Geologic Resources Potentially Affected by Geologic Sequestration Technologies

Currently, the majority of the CO_2 sequestration projects and research initiatives are focused on geologic sequestration technologies. There are three main targets for geologic sequestration including unmineable coal seams, oil and gas reserves, and saline water-bearing formations. Although other breakthrough technologies are being studied, these three viable alternatives are being implemented on both large and small scales at several project sites, as discussed below. These projects allow for the collection of actual - not theoretical or laboratory-based - data regarding the injection, migration, and interaction of the emplaced CO_2 in the various geologic formations. These data will clarify the components of a sequestration process and site characteristics that are essential to the successful implementation of the technology at multiple, varied sites at a full-scale production level.

In addition to studying the currently operating geologic sequestration projects, empirical data can also be collected from natural settings. High-purity CO_2 is produced by natural process and is geologically sequestered in formations, generally in sedimentary basins. These stable storage systems for CO_2 can be studied to obtain long-term data, and the site characteristics and interaction of the CO_2 with the surrounding environment can be used to generalize site selection criteria and clarify sequestration project operational issues.

Experts have estimated that geologic sequestration technologies could account for the disposal of hundreds to thousands of gigatons of carbon in the future (Herzog and Golomb, 2004). Validation of the technologies is underway and is aided by the various proven injection technologies currently used in industry. The projects described in the following sections account for only a small portion of the current research; however, characteristics of these projects can be used to generalize the site conditions necessary for successful geologic sequestration of CO_2 and the geologic resources that could be affected by the realization of the technologies.

3.3.5.1 Coal Seam Sequestration

There are 6 main coal producing regions in the U.S: Northern Rocky Mountains and Great Plains, Colorado Plateau, Illinois Basin, Gulf Coast, Appalachian Basin, and Alaska. Within each of these regions, there are various types of coal present, and there are areas of either abandoned underground coal mines or coal seams that are uneconomical to mine due to the location, depth, or coal grade.

Coal seam sequestration of CO_2 utilizes the same natural mechanisms that trap the naturally formed hydrocarbon gases, mainly CH_4, in the coal. The gases are adsorbed (i.e., attached by chemical attraction) to the coal in the micropores or trapped in the macropore space. These mechanisms allow the coal to store a much larger amount of gas than a comparable volume in an oil reserve due to the amount of surface area available for the adsorption. The process is analogous to the use of activated carbon filters to remove contaminants from a water supply.

The surface of the coal has a preferred affinity for adsorption of CO_2 over CH_4 at an approximate ratio between 2:1 and 3:1. Therefore, when the CO_2 is injected into the target coal seam, it displaces the CH_4, which can be recovered and sold to offset the cost of the sequestration project. This process is referred to as ECBM recovery. The amount of natural gas available in a coal seam is dependent on the rank of the coal, which is measured by the carbon content. ECBM is an important component of the sequestration technology from a financial, operational, and environmental standpoint.

For a coal seam to be suitable for CO_2 sequestration, it needs to be not only unmineable due to economic or physical restrictions, but the seam should have a high transmissivity or permeability, high effective porosity, and high storativity, among other characteristics to be described. In many cases, unmineable coal seams have low permeability, making it difficult to inject the CO_2 and extract the CH_4. Additionally, the adsorption of the CO_2 onto the coal surface can cause the coal to swell, further reducing the permeability of the seam and limiting injection and extraction. These limitations for site selection and the relationship between the required coal characteristics and the surrounding geologic resources are discussed in the following text.

3.3.5.1.1 Example Coal Seam Sequestration Project – San Juan Basin, Colorado and New Mexico

The San Juan Basin in southern Colorado and northern New Mexico is one of North America's largest natural gas fields and has been in production for approximately 75 years. Additionally, the basin contains methane-bearing coal seams that have proven to be highly productive. The basin is approximately 200 miles long from north to south and 130 miles wide from east to west, and contains geologic units ranging in age from the Cambrian to Quaternary. The formations of interest for this study are from the Upper Cretaceous time period and consist of the coal-bearing Fruitland Formation and the overlying Kirtland Shale Unit, as further described below. There are two current sequestration projects in the San Juan Basin, the Tiffany Unit CBM Project (Tiffany) and the Allison Unit Project (Allison) (BLM, 1996). Both of these sites are part of the DOE research project called "Coal-Seq" designed to study various aspects of the sequestration process (Reeves and Oudinot, 2004; Reeves et al., 2003).

At Tiffany, which is operated by BP America, N_2 has been injected to enhance the recovery of CH_4 from the Fruitland Formation since 1998; however, injection was suspended in 2002 to evaluate the results. Injecting N_2 lowers the partial pressure of the CH_4, which enables the extraction. Tiffany is the largest and longest running N_2-ECBM site in the world. Allison, operated by Burlington Resources, began injecting CO_2 in 1995 and was the first CO_2-ECBM project. Injection was suspended in 2001 to evaluate results of the study to date. The CO_2 is supplied by a natural reservoir located in the Cortez area of New Mexico (i.e., no post-combustion capture technologies are being utilized). Prior to the injection of CO_2, depressurization was used for approximately 6 years to recover CH_4 from the coal seams in the area. The combination of studying both the Tiffany and Allison units in this basin allows for conclusions to be drawn regarding the injection of post-combustion gas for ECBM because both CO_2 and N_2 are present in flue gas (Reeves and Oudinot, 2004; Reeves et al., 2003).

3.3.5.1.2 Geology in the Area of the Tiffany and Allison Units

Tiffany produces from 4 Upper Cretaceous Fruitland Formation coal seams. The average depth to the top of the shallowest coal seams is approximately 3,040 feet. The coal is classified as medium volatile bituminous and the initial temperature and pressure are recorded as 120°F and 1,600 psi, respectively. The coal has a gentle dip to the north-northeast where the units thicken slightly. The maximum permeability of the coals was determined to be on a northwest-southeast orientation, aligned with the face-cleat, and the anisotropy was estimated to be about 2.4. The average intrinsic permeability (i.e., a function of the size of the openings through which fluid moves) was determined to be 1.6 millidarcy and the average porosity was 0.8 percent (Reeves and Oudinot, 2004).

Allison also produces from three Upper Cretaceous Fruitland Formation coal seams with an average depth to the top of the shallowest seam of about 3,100 feet. The initial pressure and temperature were recorded as 1,650 psi and 120°F. The CO_2 is injected at approximately 1,500 psi (reduced from transport pressure of about 2,200 psi) and is heated prior to injection to prevent the expansion and contraction of the well during periods of no injection. The coals have a gentle dip towards the south-southwest, where the seams thicken slightly. Porosity ranges from 0.3 percent in the southwest of the project area to 0.05 percent in the northwest. Research at Allison has indicated that the absolute intrinsic permeability of the coal (ranging from 30 to 150 millidarcy) is about twice the effective permeability to gas (Reeves et al., 2003).

The Kirtland Shale overlies the Fruitland Formation, and based on the structure of the basin and the relative age of the formations, both the Fruitland and Kirtland outcrop within the basin boundaries. The Tiffany site is approximately 12 miles from the nearest Fruitland Formation outcrop. The thickness of the Fruitland Formation varies between 0 and 500 ft while the Kirtland Shale reaches a maximum thickness of approximately 1,500 ft. The Lower Kirtland Shale interval (approximately 450 ft maximum thickness in the study area) represents the caprock for the target formation. This shale unit has extremely low permeability and is aerially extensive (BLM, 1996).

3.3.5.1.3 Soils in the Area of the Tiffany and Allison Units

The typical soils in the study area are deep loams to silty-clay loams on nearly level to steep slopes. The soils have a moderate to high potential for erosion, low salinity, and moderate pH. Erosion can occur when the protective plant cover is removed for construction and transport purposes. Rainfall can then wash the topsoil to local waterways, and the increased sediment load to the waterway can increase downstream sediment deposition. Soils located on moderate to steep slopes are particularly susceptible to water erosion; however, the Tiffany and Allison sites are located in an area with generally gentle topographic relief (BLM, 1996).

3.3.5.1.4 Groundwater in the Area of the Tiffany and Allison Units

The San Juan Basin is a structural depression spanning portions of New Mexico and Colorado. Based on this structural formation and the relative location of geologic units, the Fruitland Formation is under confined groundwater conditions in the center of the basin extending to within approximately 2 miles of the outcrop. Groundwater resources for the area typically are drawn from the shallow aquifers on alluvial and terrace deposits and from sandstone aquifers in the San Jose and Animas Formations, both stratigraphically located above the Kirtland Shale Unit. These aquifers are used for both domestic and livestock/agricultural purposes, and wells can yield up to 75 gpm. In the area of the Tiffany and Allison projects, the Fruitland Formation groundwater is too deep and of too poor quality to be utilized as a water supply, and shallow, potable aquifers are isolated from the production and injection intervals by the Kirtland Shale Unit (BLM, 1996).

3.3.5.1.5 Geologic Hazards in Area of Tiffany and Allison Units

Geologic hazards in the project areas are limited. The depth of the production coal seams and the consolidated nature of the seams preclude subsidence. Landslides are not a factor as the site is located in an area of low topographic relief. Localized faulting and fracturing have occurred, especially along the margins of the San Juan Basin. However, within the central portion of the basin, in the study area, there are very few faults or fractures present. Although localized structures occur along the margins of the basin, these features do not result in a substantial hydraulic connection between overlying formations and the Fruitland Formation (BLM, 1996).

3.3.5.1.6 Preliminary Results at the Tiffany and Allison Units

Preliminary conclusions drawn from the work completed at Allison indicate that the physical processes of CO_2 sequestration are working because measurements of CO_2 concentration at the wells have been low. However, significant permeability and injectivity losses occurred with increasing CO_2 injection. Therefore, only a limited volume of CO_2 could be emplaced in the coal seams (Reeves et al., 2003).

The adsorption rate of the CO_2 onto the coal is dependent upon the temperature and pressure of the injection interval, which are functions of the depth of the interval. Additionally, the coal type affects adsorption of the CO_2. These site limitations should be added to any conceptual model created to evaluate a site for the sequestration of CO_2 in coal seams (Reeves and Oudinot, 2004).

3.3.5.1.7 Application of Coal Seam Sequestration in Other Locations

To better understand the geologic resources that may be affected by CO_2 sequestration in coal seams, it will be important to continue the testing and monitoring at the Tiffany and Allison units sites, as well as study other projects. For example, two other projects are the CONSOL Energy site in the northern panhandle of West Virginia and the RECOPOL site in the Silesian Coal Basin of Poland.

Coal seam sequestration is possible throughout the Appalachian, Interior and Western Coal Regions (Illinois, Northern Appalachian, Central Appalachian, Michigan Basins, Gulf Coast, Southwestern, Arkoma, Forest City, Black Warrior Basins, Cherokee, Powder River, Big Horn, Wind River, Hanna-Carbon, Greater Green River, Denver, Henry, SW CO, Raton, San Juan, Black Mesa, Kajpanowits, Uinta, Piceance, Williston, North Central, and Park Basins). Refer to Figure 3-13 for the coal regions and Figure 3-20 for the coal basins (as part of the coalbed methane resources) noted below. A summary of geologic site conditions necessary for successful coal seam sequestration is also discussed below.

Although the geologic resources in the potential locations of coal seam sequestration sites listed above can vary greatly, several generalizations can be made that provide some initial site selection characteristics. These characteristics were determined to be essential to minimize the effect of the sequestration activities on the geologic resources of an area.

- The target coal seams would be deep, thick, and inter-bedded with permeable sandstone strata. The seams would have high transmissivity, high effective porosity, and high storage capability.
- The coal seams would be hydrogeologically isolated from any potable aquifer (e.g., thick and laterally continuous, low permeability unit between the target coal seam and any potable water supply).
- Faults and fractures would be minimal in the project area, and any structures occurring in the area would not transmit water vertically between geologic units. No significant geologic hazards should exist in the project area.
- The coal seams would either be laterally confined to prevent potential migration of injected CO_2 (the portion of CO_2 that is not adsorbed onto the coal), or the target injection location would be laterally far away from any geologic outcrop of the coal seam (as groundwater levels decrease, the gases in the coal could be liberated at the outcrop of the coal seam).
- The sequestration site would be located near the CO_2 source to minimize the effects of the CO_2 transportation on the area.

3.3.5.2 Sequestration in Subsurface Oil and Gas Reservoirs

Reservoirs of oil and gas are geologically designed to hold the resource over long periods of time. This makes the reservoirs ideal storage locations for CO_2 sequestration. Depleted oil and gas reserves have a large volume of unoccupied space that can accommodate CO_2. Injecting CO_2 into an oil and gas reserve that is still being produced, although potentially becoming depleted, not only replaces reservoir volume, but also can enhance the secondary recovery of oil. The process of using a fluid or gas (e.g., water flood or CO_2 flood) to increase the amount of oil recovered from a reserve is referred to as EOR.

The CO_2 that is injected into a depleting oil reserve is dissolved into the remaining oil, lowering the viscosity of the oil and making it easier to extract. Using a supply of natural CO_2, this process has been incorporated into many reservoir production plans by the oil and gas industry since the 1970s. Currently, there are five large fields in the U.S. using natural sources of CO_2 for EOR. Additionally, many oil and gas companies have practiced disposing of acid gas (mainly CO_2 with some hydrogen sulfide, or H_2S) by first removing the gas from the product, compressing the gas, transporting it to an injection well, and re-injecting the acid gas into a different formation. It has been argued that this practice has less environmental impact than disposing or processing the acid gas at a facility.

The technology for injecting CO_2 for EOR is mature, especially in the Permian Basin of western Texas and eastern New Mexico. However, loss of the injected CO_2 to the formation for most EOR projects is minimized by design. As with CO_2-ECBM projects, using industry supplied anthropogenic CO_2 for EOR is a value-added benefit. Not only is the CO_2 sequestered, but the amount of oil that can be recovered from a reserve using CO_2 injection is approximately 10 to 15 percent of the original oil in the reserve.

3.3.5.2.1 Example Oil and Gas Reservoir Sequestration Project – Weyburn, Saskatchewan

The Williston Basin covers portions of Montana, North and South Dakota, Manitoba, and Saskatchewan. Hydrocarbon resources in the basin are plentiful and have been produced for many years. The Weyburn Oil Field, located in the northeast part of the Williston Basin, was discovered in 1954 and produced oil using standard methods (primary production) until 1964 when the water flood method was utilized to begin secondary recovery of oil. In 2000, Weyburn began the CO_2 flood, which will extend the life of the field by approximately 25 years making it the sixth largest recovery project in the world. The Weyburn Oil Field is currently operated by EnCana Resources and is part of an international research effort coordinated by the Canadian Petroleum Technology Research Centre and International Energy Agency Greenhouse Gas Research and Development (EnCana, 2005).

The CO_2 sequestration at the Weyburn Oil Field in Saskatchewan and Statoil's Sleipner Natural Gas Field in the North Sea are two of the largest projects actively sequestering CO_2 in geologic formations. A lignite-fired Dakota Gasification Company synfuels plant in North Dakota supplies the CO_2 to Weyburn. It is estimated that, over the approximately 25-year life of the CO_2-EOR project at Weyburn, about 16 million metric tons of CO_2 from the Dakota Gasification Facility will be injected and about 130 million barrels of oil will be produced. The study of the Weyburn project, therefore, allows scientists to determine the particular challenges associated with injecting fossil fuel supplied CO_2 rather than using a natural supply of CO_2, as is more common in EOR (Suebsiri et. al., 2004).

At the CO_2-EOR Weyburn project, it has been estimated that approximately half of the injected CO_2 remains in the oil that will not be harvested. The other half of the injected CO_2 is dissolved into the oil, making the oil easier to extract. Once back at the surface, the CO_2 is recovered, compressed, and reinjected into the formation for continued EOR and storage (IEA, 2004).

Geology in the Weyburn Project Area

The Weyburn Oil Field lies on the northeastern rim of Williston Basin, in southeastern Saskatchewan, Canada. The Williston Basin forms the southeastern extremity of the Western Canada Sedimentary Basin. These 70 square miles in Saskatchewan constitute one of the largest medium-sour crude oil reserves in Canada (Alberta Geological Survey, 1994; North Dakota, 2004).

The oil field lies at the updip end of the annular facies deposited during Mississippian time (Mississippian reservoirs account for most of the oil production in the basin). Bituminous basal carbonates store the hydrocarbon resources and are trapped by the stratigraphic layering and inter-fingering of mudstones and carbonates. Evaporites form both the top and bottom seals of the production zones. In the Weyburn field, two layers of the Midale Unit, part of the Madison Group, produce the oil. The Marly Zone is a chalk dolomite with a low permeability. The Vuggy Zone lies stratigraphically below the Marly Zone and is a highly fractured and permeable limestone. The water flood-recovery technique was quite successful in the Vuggy Zone, however, was unable to produce oil from the hydraulically tight Marly Zone. A significant amount of oil still resides in the Marly Zone, and it is hoped that the CO_2 flood is more successful for secondary recovery from this zone (Haidl et al., 2004).

The Weyburn reservoir is covered by a caprock, the Midale Evaporite, that is between 15 and 35 feet thick and is present at about 4,600 feet below ground surface (Nickel, 2004). The unit is a succession of anhydrites and dolostones. Fractures have been identified in the Midale Evaporite Unit; however, none of the fractures appear to transmit fluids. The Frobisher Evaporite is located stratigraphically below the Weyburn reservoir and ranges between 0 (in the southern portion of the field) and 23 feet thick. This evaporite consists of anhydrite with dolomudstone. Updip and north of the Weyburn reservoir is a 6 to 33 feet thick zone of alteration associated with an unconformity surface. This zone of alteration has substantially decreased porosity in the Midale Units creating a third, updip seal for the reservoir.

3.3.5.2.2 Groundwater in the Weyburn Project Area

Groundwater in the Williston Basin generally flows from the south-southwest to the north-northeast across the basin (Baker, 1999). There are two main groundwater flow regimes in the area of the Weyburn Oil Field: the Lower Paleozoic and Mississippian (e.g., Midale) Aquifer Groups, and the Mesozoic Aquifer Group. The Midale Aquifer (in the Mississippian Group) has an average intrinsic permeability of 35 millidarcy. The Jurassic and Mannville Aquifers in the Mesozoic Aquifer Group that overlie the Midale Aquifer have permeabilities that exceed 10 darcy. The Watrous Aquitard hydraulically separates the Midale Aquifer from the Jurassic Aquifer.

There appears to be very little vertical flow between aquifers as most of the flow is lateral within a given unit. The variations in water chemistry between the two groundwater flow regimes indicate that the Watrous Aquitard is competent; and the upper, less saline, higher permeability aquifers are effectively isolated from the CO_2 injection aquifer (Midale) by the Watrous Aquitard (Khan and Rostron, 2004).

3.3.5.2.3 Geologic Hazards in the Weyburn Project Area

The Williston Basin is a roughly circular-shaped area that has been subsiding very slowly over the past half-billion years. The basin contains various structural components (anticlines) creating the configuration of the basin, and its faults and fractures. Most geologic hazards present are a direct response of the natural system to anthropogenic intrusion, including mining and oil and gas production (Gibson, 1995).

3.3.5.2.4 Preliminary Results from the Weyburn Project

The Weyburn CO_2-EOR site is currently monitoring many aspects of the hydrogeologic and sequestration systems to further the understanding of the mechanisms of CO_2 storage in oil reservoirs. This project allows for the demonstration of carbon sequestration with EOR at full-scale, rather than a bench-, pilot-, or laboratory-scale. Various site selection parameters and models have been developed using the data collected at Weyburn, and several MM&V technologies are being field-tested.

Data collection began prior to the initial CO_2 flooding in 2000 to establish field characteristic prior to the injection of the CO_2. Data have also been collected during injection to compare the results. During the study, scientists conducted long-term risk assessments, completed geological and seismic studies, matched reservoir modeling against actual production results, and performed repeated and frequent sampling to understand the chemical reactions occurring within the reservoir due to CO_2 injection. Researchers with the Canadian Petroleum Technology Research Centre have succeeded in tracking the flow of the injected CO_2 underground. Mathematical models have been developed that show 100 percent of the injected gas will remain underground even after 5,000 years (Rigzone, 2004). Additionally, these models indicate that no injected CO_2 will enter the overlying drinking water sources and there will be no venting of the sequestered CO_2 to the atmosphere. Other observations and conclusions from the work completed at Weyburn are summarized below.

- The large number of oil wells in the field could present potential pathways for CO_2 escape. These wells should be monitored and, if gas is detected, mitigation efforts performed immediately.

- Seismic surveys are useful to visualize the CO_2 as it flows within the geologic units and mixes with the oil reserves.

- Mathematical models are practical tools to predict storage capacity of the reservoir and should be updated and calibrated through time as data becomes available from the injection project.

3.3.5.2.5 Application of Oil Reserve Sequestration in Other Locations

Physical characterization of the oil reserve that is to be used in any potential CO_2 sequestration project is generally complete. Most of the reservoir, geologic, and tectonic framework of the area will have been studied as part of the initial project development. However, the seals to the system (i.e., the caprock and lateral structures or geologic features that will prohibit the migration of the sequestered CO_2) will need to be studied (Figure 3-22). There are many natural analogs and current projects that can be evaluated to further the conceptualization of the geologic site conditions that could be affected by the sequestration technologies. Currently, there are at least 75 CO_2-EOR projects in the U.S. (mainly in Texas, but also in Oklahoma, Louisiana, Colorado, and Arkansas) that can be studied to gain further knowledge.

Basins with a moderate to high potential for oil reservoir sequestration projects are summarized in the following list. Refer to Figure 3-16 and Figure 3-17 for the oil and gas regions noted.

- Alaska (Northern, Central, and Southern)
- Anadarko
- Central Coastal
- Green River
- Michigan.
- Permian
- Powder River
- San Joaquin
- San Juan
- Santa Maria
- Southern Oklahoma
- Ventura
- Williston
- Wind River

Although the geologic resources in the potential locations of oil reservoir sequestration sites listed above can vary greatly, several generalizations can be made that provide some initial site selection characteristics. These characteristics were determined to be essential to minimize the effect of the sequestration activities on the geologic resources of an area. A summary of geologic conditions anticipated for successful oil reservoir sequestration is outlined on the next page.

- The oil reservoir would be deep, generally more than several thousand feet below ground surface.

- The target reservoir would be hydrogeologically isolated from any potable water aquifer (e.g., thick and laterally continuous, low-permeability unit between the reservoir and any potable water supply).

- Permeable faults and fractures should not extend through the sequestration reservoir caprock in the project area, and any structures occurring in the area would preclude water moving upward from the reservoir into shallow aquifers.

- No significant geologic hazards should exist in the project area, and active faults would be avoided.
- The oil reservoir would be laterally confined (generally by geologic structure) to prevent potential migration of injected CO_2.
- In most oil fields, there are many active and abandoned wells that extend to the target formation depth. These wells would need to be properly monitored or decommissioned in order to cut off any vertical migration pathway.
- Over-pressuring the formation due to CO_2 injection could induce seismic activity. This activity could exhibit surficial characteristics or only affect the target formation. In either case, the CO_2 could become mobile through the induced fractures; therefore, seismic activity in the vicinity of the sequestration site should be closely monitored and evaluated.
- The sequestration site would be located near the CO_2 source to minimize the effects of the CO_2 transportation on the area.

3.3.5.3 Sequestration in Saline Water-Bearing Formations

The use of saline water-bearing formations to sequester CO_2 differs from sequestration in unmineable coal seams and oil reservoirs in the following ways. First, unlike CO_2-ECBM or CO_2-EOR projects, injection of CO_2 into a saline water-bearing formation may not provide an economic benefit. In other words, many formations containing saline water may be used for CO_2 sequestration without producing a resource (e.g., petroleum) that could be sold to offset the cost of the sequestration. On the other hand, saline water-bearing formations are more ubiquitous in the U.S. than either coal seams or oil reserves. This would allow shorter transport distances for the injected CO_2 from source locations, and create a much larger potential sink for the sequestration of CO_2. Research has indicated that sequestration of CO_2 in saline water-bearing formations is the most promising long-term option available to date.

Saline water-bearing formations are layers of porous rock that are saturated with brine water. The high total dissolved solids (TDS) content of the water precludes its use for either domestic or agricultural purposes. These formations are generally found at great depths, which is an essential component for the successful sequestration of CO_2 in saline systems. Based on the current understanding of the systems, it has been determined that the CO_2 should be injected at depths greater than 2,625 feet (800 meters) not only to ensure a long flow path to the surface if the gas escapes the formation, but also to keep the CO_2 in the dense phase. At this depth, the pressure and temperature present are such that the gas will not exist in either a gas or liquid phase, but rather an immiscible supercritical phase with high density. The specific gravity of the CO_2 is lower than that of the brine so the CO_2 rises to the top of the reservoir. The CO_2 can be further trapped by the solubility and mineral trapping mechanisms (e.g., dissolution of CO_2 into fluids and the reaction of CO_2 with minerals present in the host formation to make stable compounds such as carbonates) present in the saline water-bearing formation. This ensures efficient storage of the CO_2 and implies that the CO_2 may be fixed or dissolved before reaching a basin margin.

Characterization of the saline water-bearing formation may require more initial work than for other geologic sequestration sites as less work has been completed on the sequestration target historically. Often, however, saline water-bearing formations occur in the same area as oil and gas reserves, where data are plentiful.

Table 3-25 depicts some of the most prominent deep saline formations in the U.S. These formations include:

- Arbuckle Group (Oklahoma)
- Cape Fear (South Carolina Coastal Plain)
- Carbonate Basin Fill (Basin and Range)
- Cedar Keys/Larson (Florida)
- Fox Hills (Powder River Basin)
- Frio (Gulf Coast Basin)
- Glen Canyon (Kaiparowitz Basin)
- Granite Wash (Palo Duro Basin)
- Jasper (Gulf Coast Basin)
- Lower Potomac (North Atlantic Coast)
- Lyons Sandstone (Denver Basin)
- Madison Formation (Williston Basin)
- Morrison (San Juan Basin)
- Mt. Simon (Ohio-Michigan area)
- Oriskany Sandstone (Appalachian Basin)
- Paluxy Formation (East Texas Basin)
- Pottsville (Black Warrior Basin)
- St. Peter (Illinois Basin)
- Tuscaloosa (Coastal Alabama)

Summaries of most of these formations as they relate to potential carbon sequestration activities are available in the Phase I Topical Report "Technical Summary: Optimal Geological Environments for Carbon Dioxide Disposal in Brine Formations (Saline Formations) in the U.S." by the Bureau of Economic Geology, University of Texas as Austin, sponsored by NETL (available at http://www.beg.utexas.edu/environqlty/co2seq/finalreport.pdf).

Several generalizations can be made that provide some initial site selection characteristics. A summary of geologic conditions anticipated for successful sequestration in saline water-bearing formations is outlined below.

- The target saline water-bearing formation would be deep underground (at least 2,625 ft, or 800 m below ground surface) to allow injected CO_2 to stay in the dense phase.
- The target formation would be hydrogeologically isolated from any potable aquifer (e.g., thick and laterally continuous, low-permeability unit between the reservoir and any potable water supply).
- Faults and fractures would be minimal in the project area, and any structures occurring in the area would not transmit water vertically between geologic units. No significant geologic hazards should exist in the project area.
- The saline water-bearing formation would be laterally confined (generally by geologic structure) to prevent potential migration of injected CO_2. Alternatively, the formation will be of great enough lateral and areal extent that the injected CO_2 would have time to undergo solubility or mineral trapping in the groundwater flow regime.

- Many saline water-bearing formations occur in conjunction with oil and gas resources. In most oil fields, there are many active and abandoned wells that extend to the target formation depth and beyond. These wells would need to be properly monitored or decommissioned in order to cut off any vertical migration pathway.
- The sequestration site would be located near the CO_2 source to minimize the effects of the CO_2 transportation on the area.

Saline formations under current study by the Regional Partnerships are shown in Figure 3-24.

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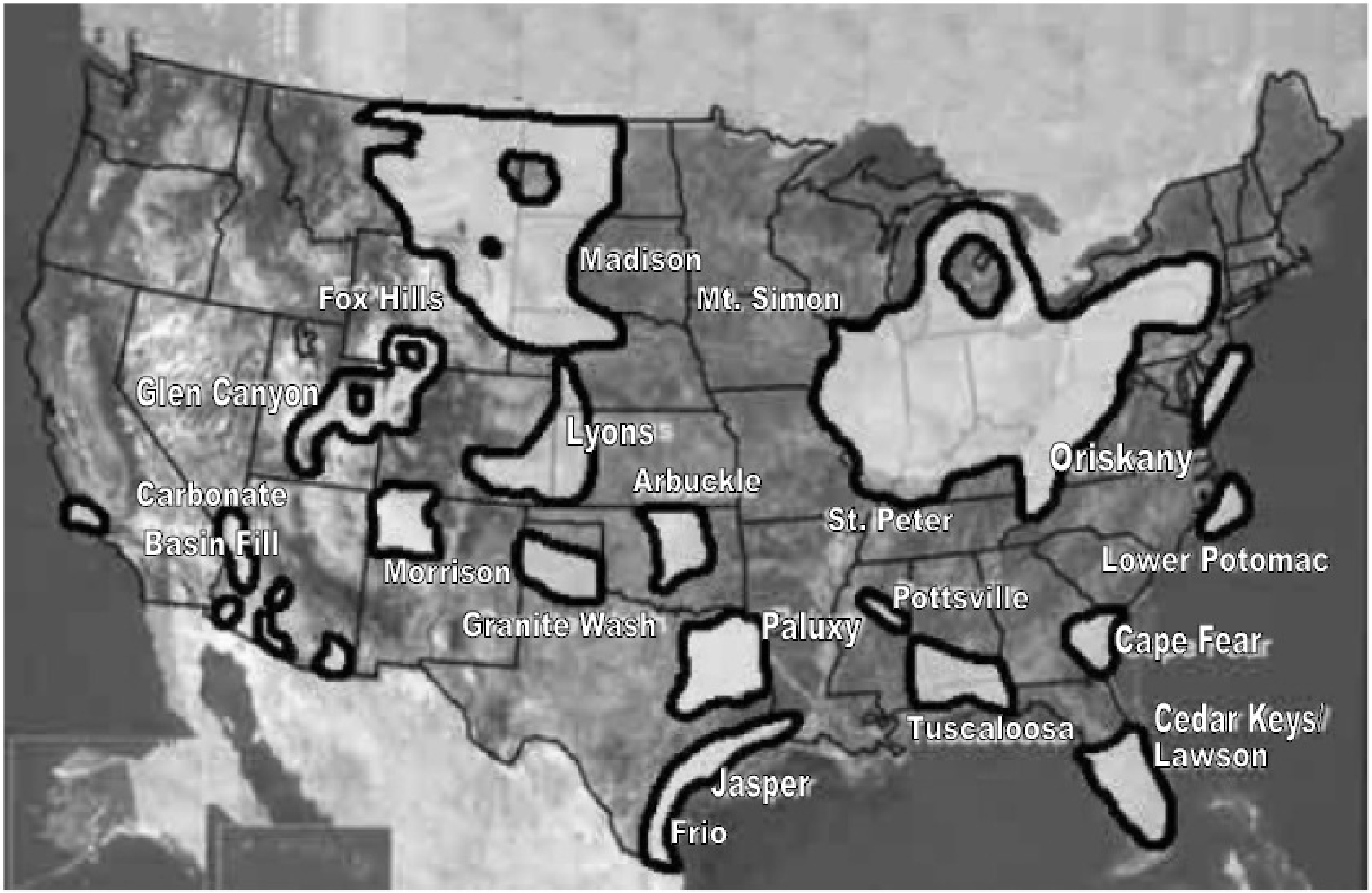

Source: DOE, 2002.

Figure 3-23. Deep Saline Formations in the U.S

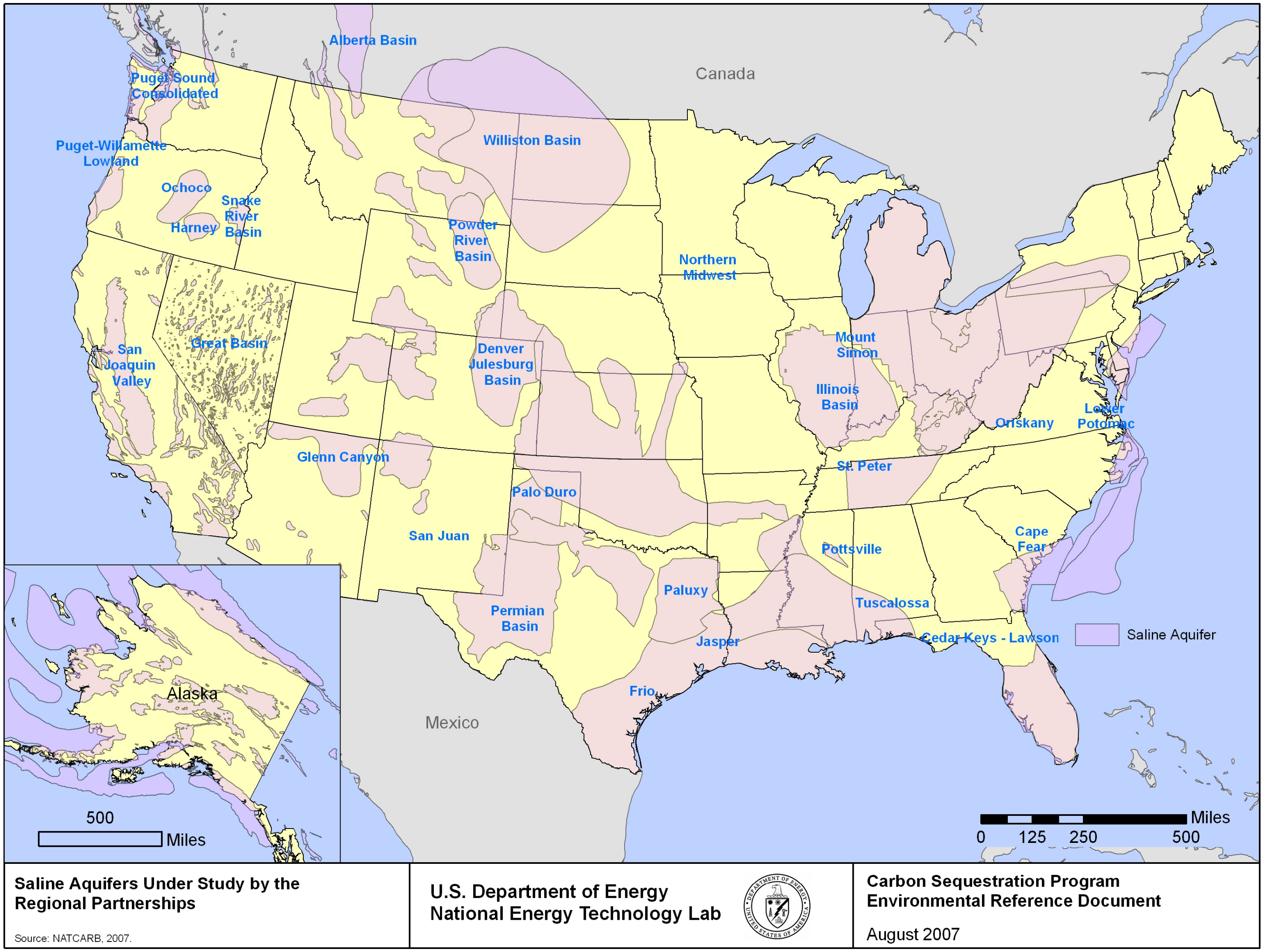

Figure 3-24. Saline Formations under Evaluation by the Regional Partnerships

3.3.5.3.1 Example of a Saline Water-Bearing Formation Sequestration Project – Frio Formation, Liberty County, Texas

The University of Texas at Austin's Bureau of Economic Geology is currently conducting a small-scale field test of the saline water-bearing formation sequestration technologies. The test site is located in the South Liberty Oil Field about 40 miles inland of the Gulf of Mexico, just northeast of Houston. The oil field was discovered in 1925 and produced in various stages through most of the 1900s. There are currently about 650 wells in the oil field, some producing and some abandoned.

The target formation, the Frio Formation, is about 5,000 feet below ground surface and is stratigraphically above the depleted oil reserve in the area. A new injection well was recently completed to 5,753 ft below ground surface and an older well was modified to become an observation well approximately 100 feet updip from the injection point (Techline, 2004). The injected CO_2 was supplied from a BP oil refinery in Texas City, Texas, and in October 2004, approximately 1,600 tons of CO_2 was injected during the 9-day test (Hovorka et al., 2005).

3.3.5.3.2 Geology in the Frio Brine Pilot Project Area

The Frio Project Site is located in an area of low topographic relief in the lower coastal plain of the Gulf of Mexico on the terrace above the Trinity River (NETL, 2003). The area gently dips towards the Gulf and is transected every few miles by northeast-trending (southeast down drop) growth faults. Additionally, there are numerous salt domes in the area that disrupt the geology and structures.

The injection zone is the Frio Sandstone, which contains a brine groundwater formation, located on the southwest flank of the South Liberty Salt Dome. The Frio is laterally limited within a fault-bounded compartment. There is approximately 200 feet of shale (Anahuac Shale Unit) above the Frio, creating the caprock for the system, and about 4,200 feet of inter-bedded sandstones and shales above the Anahuac Formation. The total thickness of the Frio is about 2,000 feet; however, the injection zone is near the top of the unit (the injection well is screened from 5,053 to 5,073 feet below ground surface) (Techline, 2004). Hydrocarbons were produced from the interval between 8,000 and 9,000 feet below ground surface, and a thick shale unit lies stratigraphically between the depleted hydrocarbon zone and the brine system.

The 70-feet thick test interval has an average porosity of 27 percent and a measured intrinsic permeability between 50 and 242 millidarcy, as reported in June 2004. More recent testing reported April 2005 indicates an inter-well permeability of approximately 2.3 darcy. In this area, the Frio dips approximately 16 degrees to the south. The pressure and temperature recorded in the injection interval are about 2,211 psi and 135°F. The salinity in the Frio at this location ranges from 100,000 to 125,000 ppm, equivalent to milligrams per liter.

3.3.5.3.3 Soils in the Frio Brine Pilot Project Area

There are generally three soil units in the area of the Frio Project Site. In the uplands, the dominant soils are thick with textures ranging from very fine sandy loam to clay, and potentially sandy clay loam to clay. The Woodville fine sandy loams are found on the bluff between the upland and the Trinity River flood plain. Very deep, wet, and poorly drained clay to silty clay soils of the Kaman unit are located on the Trinity River flood plain. Additionally, alluvium deposits are found in the area, especially on the flood plain. The dominant soil texture at the site is sandy loam.

3.3.5.3.4 Groundwater in the Frio Brine Pilot Project Area

Groundwater and surface water systems are generally interconnected, and the location of the main channel of the Trinity River only about 1.5 miles east of the Frio Project Site would suggests that there are areas of groundwater near the surface (potentially perched). Fresh groundwater in the area is found near the surface in the alluvium and Beaumont units and in the Upper and Lower Chicot and Evangeline Formations. The base of the useable groundwater (groundwater with concentrations of TDS less than

3,000 ppm) in the area is at about 2,200 feet below ground surface. Below the Evangeline Aquifer is the Burkeville confining unit, which seems to effectively separate the useable groundwater from marginal quality groundwater (concentrations of TDS less than 10,000 ppm) below. This zone of marginal quality groundwater extends to about 3,400 ft below ground surface, approximately 1,600 feet above the CO_2 injection zone in the Frio. Additionally, 200 feet of the Anahuac Shale Formation lie stratigraphically between the useable groundwater and the injection zone (Techline, 2004).

3.3.5.3.5 Geologic Hazards in the Frio Brine Pilot Project Area

As described above, there are some faults and fractures in the area of the Frio test site. Based on evaluations conducted in conjunction with the oil and gas production in the area, these faults act as barriers to compartmentalize the hydrostratigraphy of the area, rather than as conduits for fluid or gas migration. It has yet to be determined how these faults and fractures will behave with the increased pressure from the injected CO_2. Additionally, with the site located on the Trinity River flood plain, there is the potential for flooding in the project area.

3.3.5.3.6 Preliminary Results from the Frio Brine Pilot Project

Prior to the initiation of the CO_2 injection in October 2004, various geologic and hydrogeologic characteristics were measured and monitored to create a baseline for the later comparison of data collected during and following the injection. These baseline data collection methods included the following;

- Collecting groundwater samples and using the laboratory analyses results to generate a site-specific model of the aqueous geochemistry.
- Conducting wire-line logging, cross-well seismic, cross-well electromagnetic imaging, and vertical seismic profiling to determine the configuration of the subsurface between the injection and observation wells.
- Hydrologic testing in two wells to assess various groundwater movement characteristics.
- Surface water and gas monitoring to establish baseline levels.

During the 9-day injection test and following the injection, monitoring was repeated and extensive methods were used to monitor the movement of the injected CO_2 (Techline, 2004). Three (3) tracers were utilized to follow the travel path of the injected CO_2.

Preliminary results indicate that the pressure domain in the test site was more complex than hypothesized due to the producing wells in the South Liberty Oil Field. Additionally, the modeling and results analyses were complicated by the heterogeneity present in the sandstones.

3.3.5.3.7 Application of Saline Water-Bearing Formation Sequestration in Other Locations

Studying the characteristics and results of the CO_2 injection test at the Frio Project Site will yield valuable information for much of the Gulf Coast region. Similar salt water-bearing formations exist in the region from coastal Alabama to Mexico, and many of these formations are located near refineries and industrial processing plants that produce large amounts of CO_2 that could be used in sequestration projects. The high-permeability, large-volume sandstones characteristic to this region are ideal for sequestration projects, assuming competent seals are present. Using the short-term, pilot-test results obtained at Frio, scientists will be able to better define variables that control CO_2 injection and migration. The data can be used in project conceptualization and model calibration in the planning, development, and monitoring phases of additional sequestration projects.

In addition to the Frio project, there are many other projects that can be studied to further the knowledge of saline water-bearing formation sequestration of CO_2 such as the Midwestern U.S. Project operated by Battelle, and the Statoil Project at the Sleipner West Natural Gas Production Facility (injecting deep in the Utsira Formation, a saline water-bearing formation beneath the North Sea at approximately 3,280 ft deep).

3.3.5.4 Basalt Formation Sequestration

Basalt formations exist throughout the U.S., and elsewhere in many areas around the world. In some locales, these formations may be attractive targets for CO_2 sequestration, if they have relatively high permeability, because they appear to have favorable geochemical properties for converting the injected CO_2 to solid mineral forms, and thus over long periods may permanently isolate the CO_2 from the atmosphere (NETL, 2004). Basalt is a type of volcanic rock that is formed when magma high in aluminum, silica, calcium, iron and magnesium extrudes to the ground surface, flows out as lava, and is solidified. Commonly, basalt rock formations have porous characteristics (including cooling joints and pore spaces caused by rapid cooling and escape of gases at the surface) that create permeability in an otherwise solid rock mass. Coarse rubble zones, caused by varied cooling and flowing rates, are found above and below more dense rock. Often sand and gravel is deposited on top of or within the rubble zones, which create the relatively high bulk permeability. However, the centers of the lava flows are dense, typically unfractured and thus much less permeable. Stream flow deposits and zones of blocky rubble usually follow the flow trend so the highest permeability of the formations is parallel to the lava flow direction. The permeability of the basalt can decrease with geologic time as alteration by deep burial or the influx of cementing fluids fills available pore spaces and fractures (Freeze and Cherry, 1979).

Flood basalt formations are, by definition, multiple lava flows of huge volume (on the order of 5-10 cubic km or more) while plain basalt formations have individual flow volumes generally much less than 1 cubic km (USGS, 2005). There is evidence that aquifers in various flood and plain basalt flows are isolated, however the integrity of those natural seals with respect to the injection of CO_2 would need to be investigated at a field-scale test (Manancourt and Gale, 2004).

The theory behind sequestering CO_2 in basalt formations includes the chemical, or mineralogical, trapping of the injected CO_2. Under certain reservoir conditions, the CO_2 reacts with the minerals in the formation releasing cations (mainly calcium, magnesium, and iron) into solution and precipitating as carbonate minerals (e.g., calcium carbonate, $CaCO_3$) (Schaef, et al., 2004).

Major basalt formations in the U.S are shown in Figure 3-25 and include:

- Keweenawan Formation: The Keweenawan formation was formed during the rift event that created the Lake Superior Craon (UWM, 2005). The system is approximately 35,000 feet thick, however, the total thickness of the basalt units is unknown due to the formation abutting to the Keweenawan Fault (Butler and Burbank, 1929). About 24,000 cubic miles of lava extruded (CRR, 2005). The typical Keweenawan basalt flow grades from olivine composition through andesitic to rhyolitic basalt (Butler and Burbank, 1929).
- East Continental Rift Zone: The East Continental Rift Zone is a basin filled with sedimentary and volcanic rocks (UK, 2005). The mafic volcanic rocks are fractured, however, the extent of the fracturing is unknown (Drahovzal and Harris, 2004). The Newark Supergroup was accumulated in a half-graben associated with extensional faulting (Geowords, 2005; Schlische, 1992). There are three quartz-normative tholeiitic basalt flows interbedded with lake-level sediment cycles Hook Mountain, approximately 360 feet thick; Preakness, approximately 820 feet thick; and Orange Mountain, approximately 490 feet thick (Schlische, 1996 and 1992).

Figure 3-25. Primary Basalt Formations

Source: Battelle, 2005.

- Southeast Rift Zone: This zone is a fault-bounded extensional basin that is part of the North American rifted margin. This rift zone formed during the breakup of the Pangean supercontinent and the formation of the Atlantic Ocean. These basalt formations, also known as the South Georgia Rift Formations or the Clubhouse Crossroads Basalts, are part of the Central Atlantic Magmatic Province and are classified as tholeiitic basalts. The basalt composition has high sodium and potassium with low silica group inclusions only in the stratigraphically lower Clubhouse Crossroads basalt (Branton et al, 2001). The basalt flows are areally extensive with an implied area greater than 38,000 square miles (McBride et al, 1989).

- Southern Nevada Volcanics: The Southern Nevada Volcanics basalt formations are thickest in the central part of the flows (about 650 feet thick) with the individual flows generally less than 30 feet thick. The composition of these basalts ranges from calc-alkaline andesite, to dacite, to olivine (USGS, 2005).

- Northern California Volcanics: The Northern California Volcanics are a massive platform of basalts that overlies the western Cascades (Siskiyous, 2005). Known as the High Cascades, the formations are a result of subduction-related volcanism and consist mainly of basalt and basaltic andesite, which are magnesium rich (Siskiyous, 2005 and USGS, 2005). Basalt flows are also present in the vicinity of Mt. Lassen, a volcano in northern California, which is located at the southern end of the Cascade Arc (UW, 2005).

- Snake River Plain: The Snake River Plain basalt formation is found in southern Idaho and western Oregon. The normal fault-bounded basin is filled with plain basalt formations interbedded with lakebed sediments covering an area of 8,000 square miles with basalts flows on an average of 5,000 ft thick (ISU, 2005 and USGS, 2005). These basalt flows consist of sequences of thin, individually cooled units less than 3 ft to greater than 30 ft thick (ISU, 2005). The composition of formation varies, but is mainly silicic and basaltic volcanic, with rhyolite more abundant than basalt. In this area, the rhyolite and basalt flows often alternate with deposits of extensive volcanic tuff and ash flows (ISU, 2005). Many of the faults and large fracture zones extend into the plain from the basin margins (ISU, 2005).

- Columbia River Basalt Group (CRBG). The Columbia River Basalt Group (CRBG) is located in northern Oregon and southern Washington. This formation is one of the largest and most studied basalt formations in the world (WDGER, 2005). The four formations that comprise the CRBG cover over 63,000 square miles and have a volume of almost 42,000 cubic miles (WDGER, 2005). The thickness of these formations exceeds 6,000 ft in some locations (USGS, 2005). More than 300 individual, high-volume lava flows have been identified with an average volume of about 140 cubic miles (USGS, 2005 and UND, 2005). Most of the flows in the CRBG are tholeiitic basalts, which are typically quite dense. Limited zones of vesicular basalt are also interbedded with more extensive river-deposited sediments between flows (UND, 2005 and Freeze and Cherry, 1979). The relatively dense, unfractured portions of the basalt exhibit a low permeability and generally impede groundwater flow, thus acting as an aquitard (Freeze and Cherry, 1979). There is a small injection test planned (approximately 3,000 tons of CO_2) at a depth of about 3,000 ft in the Grande Roude member of the CRBG in eastern Washington (BSRCSP, 2005). Preliminary calculations indicate that the CRBG formations have favorable geochemical properties for converting injected CO_2 into carbonate minerals (PNL, 2005).

Although the geologic characteristics in the potential locations of basalt formation sequestration project sites vary greatly, several generalizations can be made that provide some initial site selection characteristics. A summary of geologic conditions anticipated for successful sequestration in basalt formations is outlined below. Since the use of basalt formations to sequester CO_2 has not been extensively studied, much of those data required for a successful project design are not available. Those necessary data include injectivity, storage capacity, and rate of conversion (NETL, 2004).

- The target basalt formation would be deep underground to allow the injected CO_2 to stay in the dense phase.

- The target formation would be hydrogeologically isolated from any potable aquifer (e.g., by a thick and laterally continuous, low-permeability unit between the basalt reservoir and shallower aquifers).

- Extensive or pervasive faults and fractures would be minimal in the project area, and any structures occurring in the area would not transmit water vertically between geologic units. Sites would be selected to avoid significant geologic hazards. If unavoidable, geologic hazards would be recognized during site characterization and the potential impacts would be mitigated by effective project design.

- The sequestration site would be located near the CO_2 source to minimize the effects of the CO_2 transportation to the area.

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3.4 SURFACE WATER RESOURCES

This section describes the surface water resources that may be affected by carbon sequestration projects. In this section, the term surface water is defined as rivers, streams, lakes, ponds, reservoirs, wetlands, estuaries and coastal waters. Groundwater is addressed in the section on geologic resources.

Protective water quality standards are important for the conservation and enhancement of fish, wildlife, and their habitats and for the continuing benefit of the American people. The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The goal of this law is to establish national water quality standards that provide for the protection of fish, shellfish, and wildlife as well as providing safe recreational use of the nation's water bodies.

Poor water quality can harm species and habitats, and must be assessed in activities such as wastewater discharge. Many factors are known to cause poor water quality including temperature, sedimentation, runoff, erosion, dissolved oxygen, pH, decayed organic materials, pesticides, and an array of other toxic and hazardous substances (USFW, 2004).

The EPA's 2000 Report to Congress on the status of U.S. water quality reported the following two leading causes of surface water pollution nationwide (EPA, 2000):

- Pollution from urban and agricultural land that is transported by precipitation and runoff (called nonpoint source pollution) is the leading source of impairment.
- Siltation, nutrients, bacteria, metals (primarily mercury) and oxygen-depleting substances are among the top causes of impairment.

Some of the problems caused by toxic and pathogen contamination include fish, wildlife and shellfish consumption advisories, drinking water closures, and recreational restrictions. EPA's National Listing of Fish and Wildlife Advisories database listed 2,838 advisories in effect in 2000. Ten (10) of 28 coastal states reported prohibited, restricted or conditionally approved shellfish harvesting in 1,630 square miles of estuarine waters. Thirteen states and tribes identified 233 sites where contact recreation was restricted at least once during the reporting cycle (EPA, 2000).

States, participating tribes and other jurisdictions measure attainment of the Clean Water Act goals by comparing monitoring data to the narrative and numeric criteria they have adopted to ensure support of each use designated for each specific water body. These uses include: aquatic life support, drinking water supply, fish consumption, shellfish harvesting, primary recreation (swimming), secondary recreation, agriculture, ground water recharge, wildlife habitat and cultural. Assessments are normally based upon five broad types of monitoring data: biological integrity, chemical, physical, habitat and toxicity data (EPA, 2000). In EPA's 2000 Report to Congress, an estimated 39 percent of U.S. rivers and streams were found impaired for one of more uses. Similarly, 45 percent of the more than 41 million acres of lakes and streams nationwide and 51 percent of estuaries were reported to be impaired for one or more uses (see Table 3-5). Table 3-6 provides information on surface water resources in each state.

Table 3-5. Surface Water Resources in the U.S.

Surface Water Resources	Entire United States	Percent Impaired for One or More Uses
Total Miles of Rivers and Streams	3,655,192	39%
Total Lake, Reservoir and Pond Acres	41,410,351	45%
Estuaries, Total Square Miles	71,709	51%
Ocean Shorelines, Total Miles	65,754	Not Evaluated

Source: EPA, 1998 and EPA, 2000.

Table 3-6. Surface Water Resources in Each State

State	Rivers and streams (miles)	Lakes, Reservoirs, and Ponds (acres)	Estuaries (square miles)	Ocean shoreline (miles)
Alabama	77,274	490,472	610	337
Alaska	365,000	12,787,200	33,204	36,000
Arizona	127,505	400,720	0	0
Arkansas	87,617	514,245	0	0
California	211,513	1,672,684	2,139	1,609
Colorado	107,403	164,029	0	0
Connecticut	5,830	64,973	612	380
Delaware	2,506	2,954	449	25
District of Columbia	39	238	6	0
Florida	51,858	2,085,120	4,437	8,460
Georgia	70,150	425,382	854	100
Idaho	115,595	700,000	0	0
Illinois	87,110	309,340	0	0
Indiana	35,673	142,871	0	0
Iowa	71,665	161,366	0	0
Kansas	134,338	188,506	0	0
Kentucky	49,105	228,385	0	0
Louisiana	66,294	1,078,031	7,656	397
Maine	31,752	987,283	2,852	5,296
Maryland	8,789	77,965	2,522	32
Massachusetts	8,229	151,173	223	1,519
Michigan	51,438	889,600	0	0
Minnesota	91,944	3,290,101	0	0
Mississippi	84,003	500,000	760	245
Missouri	51,978	293,305	0	0
Montana	176,750	844,802	0	0
Nebraska	82,258	280,000	0	0
Nevada	143,578	533,239	0	0
New Hampshire	10,881	168,017	21	18
New Jersey	8,050	72,235	725	127
New Mexico	110,741	997,467	0	0
New York	52,337	790,782	1,530	120
North Carolina	37,662	311,071	3,121	320
North Dakota	54,427	714,910	0	0
Ohio	29,113	188,461	0	0
Oklahoma	78,778	1,041,884	0	0
Oregon	115,472	618,934	206	362

State	Rivers and streams (miles)	Lakes, Reservoirs, and Ponds (acres)	Estuaries (square miles)	Ocean shoreline (miles)
Pennsylvania	83,161	161,445	0	0
Rhode Island	1,383	21,796	151	79
South Carolina	29,794	407,505	401	190
South Dakota	9,937	750,000	0	0
Tennessee	61,075	538,060	0	0
Texas	191,228	1,994,600	2,394	624
Utah	85,916	481,638	0	0
Vermont	7,099	228,920	0	0
Virginia	49,460	149,982	2,494	120
Washington	70,439	466,296	2,904	163
West Virginia	32,278	22,373	0	0
Wisconsin	55,000	944,000	0	0
Wyoming	108,767	325,048	0	0

Source: EPA, 2000.

3.4.1 Wetlands

In the 1600s, more than 220 million acres of wetlands are thought to have existed in the lower 48 states. Since then, extensive losses have occurred, and over half of the original wetlands have been drained and converted to other uses. The years from the mid-1950s to the mid- 1970s were a time of major wetland loss, but since then the rate of loss has decreased.

Between 1986 and 1997, an estimated 58,500 acres of wetlands were lost each year in the conterminous U.S. Various factors have contributed to the decline in the loss rate including implementation and enforcement of wetland protection measures and elimination of some incentives for wetland drainage. Public education and outreach about the value and functions of wetlands, private land initiatives, coastal monitoring and protection programs, as well as wetland restoration and creation actions have also helped reduce overall wetland losses (EPA, 2003).

The lower 48 states contained an estimated 105.5 million acres of wetlands in 1997. This is an area about the size of California. In the 1980s, an estimated 170 to 200 million acres of wetland existed in Alaska (covering slightly more than half of the state), while Hawaii had 52,000 acres. Next to Alaska, Florida (11 million), Louisiana (8.8 million), Minnesota (8.7 million), and Texas (7.6 million) have the largest wetland acreage. Total wetland area and historic losses for each state are listed in Table 3-8 in Section 3.5 Biological Resources.

3.4.2 Rivers

A list of major rivers within the U.S. is provided in Table 3-7.

Table 3-7. Major Rivers of the United States

River	Length	Flows Into	States Traversed or Bordering
Alabama-Coosa	600 mi (966 km)	Mobile River	GA, AL
Altamaha-Ocmulgee	392 mi (631 km)	Atlantic Ocean	GA
Apalachicola – Chattahoochee	524 mi (843 km)	Gulf of Mexico	NC, SC, GA, AL, FL
Arkansas	1,459 mi (2,348 km)	Mississippi River	CO, KS, OK, AR
Brazos	923 mi (1,485 km)	Gulf of Mexico	NM, TX
Canadian River	906 mi (1,458 km)	Arkansas River	CO, NM, TX, OK

River	Length	Flows Into	States Traversed or Bordering
Cimarron	600 mi. (966 km)	Arkansas River	NM, OK
Colorado	862 mi. (1,387 km)	Matagorda Bay	CO, UT, AZ, NV, CA
Columbia	1,243 mi (2,000 km)	Pacific Ocean	WA, OR
Colville	350 mi (563 km)	Beaufort Sea	AK
Connecticut	407 mi (655 km)	Long Island Sound	VT, NH, MA, CT
Cumberland	720 mi (1,159 km)	Ohio River	KY, TN
Delaware	390 mi (628 km)	Delaware Bay	NJ, PA, NY
Gila	649 mi. (1,044 km)	Colorado River	NM, AZ, CA
Green	730 mi (1,175 km)	Colorado River	ID, WY, UT
Illinois	420 mi (676 km)	Mississippi River	IL
James	710 mi (1,143 km)	Missouri River	ND, SD, NE
Kanawha-New	352 mi (566 km)	Ohio River	NC, VA, WV
Kansas	743 mi (1,196 km)	Missouri River	CO, KS
Koyukuk	470 mi (756 km)	Yukon River	AK
Kuskokwim	724 mi (1,165 km)	Kuskokwim Bay	AK
Licking	350 mi (563 km)	Ohio River	KY, OH
Little Missouri	560 mi (901 km)	Missouri River	WY, MT, SD, ND
Milk	625 mi (1,006 km)	Missouri River	MT
Mississippi	2,348 mi (3,779 km)	Gulf of Mexico	MN, WI, IA, MO, IL, KY, AR, TN, LA, MS
Mississippi-Missouri-Red Rock	3,710 mi (5,970 km)	Gulf of Mexico	MT, ND, SD, NE, IA, MO, KS, IL, TN, AR, MS, LA
Missouri	2,315 mi (3,726 km)	Mississippi River	MT, ND, SD, NE, KS, MO
Missouri – Red Rock	2,540 mi (4,090 km)	Mississippi River	ID, MT, ND, SD, NE, IA, KS, MO
Mobile-Alabama-Coosa	645 mi (1,040 km)	Mobile Bay	GA, AL
Neosho	460 mi (740 km)	Arkansas River	KS, OK
Niobrara	431 mi (694 km)	Missouri River	WY, NE
Noatak	350 mi (563 km)	Kotzebue Sound	AK
North Canadian	800 mi (1,290 km)	Canadian River	NM, TX, OK
North Platte	618 mi (995 km)	Platte River	CO, WY, NE
Ohio	981 mi (1,579 km)	Mississippi River	PA, OH, WV, IN, KY, IL
Ohio-Allegheny	1,306 mi (2,102 km)	Mississippi River	PA, OH, IN, IL
Osage	500 mi (805 km)	Missouri River	KS, MO
Ouachita	605 mi (974 km)	Red River	AR, LA
Pearl	411 mi (661 km)	Gulf of Mexico	MS, LA
Pecos River	926 mi (1,490 km)	Gulf of Mexico	NM, TX
Pee Dee-Yadkin	435 mi (700 km)	Winyah Bay	NC, SC
Pend Oreille-Clark Fork	531 mi (855 km)	Columbia River	MT, ID, WA
Platte	990 mi (1,593 km)	Missouri River	CO, WY, NE
Porcupine	569 mi (916 km)	Yukon River	AK
Potomac	383 mi (616 km)	Chesapeake Bay	MD, VA, WV
Powder	375 mi (603 km)	Yellowstone River	MT, WY
Red	1,290 mi (2,080 km.)	Mississippi River	NM, TX, AR, LA
Red (also called Red River of the North)	545 mi (877 km)	Lake Winnipeg	MN
Republican	445 mi (716 km)	Kansas River	CO, NE, KS
Rio Grande	1,900 mi (3,060 km.)	Gulf of Mexico	CO, MN, TX
Roanoke	380 mi (612 km)	Albemarle Sound	VA, NC

River	Length	Flows Into	States Traversed or Bordering
Sabine	380 mi (612 km)	Sabine Lake	TX, LA
Sacramento	377 mi (607 km.)	Suisun Bay	CA
Saint Francis	425 mi (684 km)	Mississippi River	MO, AR
Salmon	420 mi (676 km)	Snake River	ID
San Joaquin	350 mi (563 km)	Suisun Bay	CA
San Juan	360 mi (579 km)	Colorado River	CO, NM, UT
Santee-Wateree-Catawba	538 mi (866 km)	Atlantic Ocean	NC, SC
Smoky Hill	540 mi (869 km)	Kansas River	CO, KS
Snake River	1,038 mi (1,670 km)	Columbia River	ID, OR, WA
South Platte	424 mi (682 km)	Platte River	CO, NE
Stikine	379 mi (610 km)	Stikine Strait	AK
Susquehanna	444 mi (715 km)	Chesapeake Bay	PA, MD, DE
Tanana	659 mi (1,060 km)	Yukon River	AK
Tennessee	652 mi (1,049 km)	Ohio River	TN, GA, AL, MS, KY
Tennessee-French Broad	886 mi (1,417 km)	Ohio River	KY, TN, AL, NC
Tombigbee	525 mi (845 km)	Mobile River	MS, AL
Trinity	360 mi (579 km)	Galveston Bay	TX
Wabash	512 mi (824 km)	Ohio River	OH, IL, IN
Washita	500 mi (805 km)	Red River	TX, OK
White	722 mi (1,160 km)	Mississippi River	AR
Wisconsin	430 mi (692 km)	Mississippi River	WI
Yellowstone	692 mi (1110 km)	Missouri River	ID, WY, MT
Yukon River	1,979 mi (3,185 km)	Bering Sea	AK

Source: Infoplease, 2004.

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3.5 BIOLOGICAL RESOURCES

This section describes the ecological resources that may be affected by carbon sequestration research projects and future commercial deployment. This discussion is based on ecoregions of the U.S. as presented in the National Atlas (DOI, 2000).

Ecoregions, or ecosystems of regional extent, are areas that share common climatic and vegetation characteristics. The U.S. Forest Service developed the following four-level hierarchy to differentiate ecoregions (USFS, 2004):

- Domains - Areas of related climates – differentiated based on precipitation and temperature.
- Divisions - Representative climates within domains – differentiated based on precipitation levels and patterns as well as temperature.
- Provinces - Areas within a division differentiated based on vegetation or other natural land covers. Mountainous areas that exhibit different ecological zones based on elevation are identified at the province level.
- Sections - Subdivisions of provinces based on terrain features.

Four ecological domains (humid temperate, dry, humid tropical and polar) are used for worldwide ecoregion classification and all four appear in the continental U.S. (Figure 3-26). The following discussion of biological resources of the U.S. is based primarily on these domains (Bailey, 1995).

3.5.1 Vegetation

The following paragraphs summarize the vegetation in each of the ecological domains across the continental U.S., including Alaska.

3.5.1.1 Humid Temperate Domain

The humid temperate domain is located in the middle latitudes (30 to 60 degrees North), where the climate is governed by both tropical and polar air masses. The domain is characterized by pronounced seasons, with strong annual cycles of temperature and precipitation including a distinctive winter season.

In the coastal ranges of the Pacific Northwest, Douglas fir, red cedar, and spruce grow to great heights. A combination of wet winters with dry summers, as found in central California, produces a distinctive natural vegetation of hard leaved evergreen trees and shrubs called sclerophyll forest. Trees and shrubs must withstand the severe summer drought (2 to 4 rainless months) and severe evaporation.

This domain encompasses the eastern half of the U.S. Much of the sandy coastal region of the Southeastern U.S. is covered by second-growth forests of longleaf, loblolly, and slash pines. Inland areas have deciduous forest. Needleleaf and mixed needleleaf-deciduous forests grow throughout the colder northern parts of the humid temperate domain, extending into the mountain regions of the Adirondacks and northern New England.

In the Midwestern portion of the U.S., vegetation is known as winter deciduous forests, dominated by tall broadleaf trees that provide a continuous dense canopy in summer, but shed their leaves completely in winter. Lower layers of small trees and shrubs are weakly developed. In spring, a luxuriant ground cover of herbs quickly develops, but is greatly reduced after trees reach full foliage and shade the ground.

3.5.1.2 Dry Domain

The essential feature of a dry climate is that annual losses of water through evaporation at the earth's surface exceed annual water gains from precipitation. Areas with a semiarid climatic regime are characterized by vegetation called steppe, or shortgrass prairie, and semidesert. Typical steppe vegetation consists of numerous species of short grasses that usually grow in sparsely distributed bunches. Scattered shrubs and low trees sometimes grow in the steppe; all gradations of cover are present, from semidesert to woodland. Because ground cover is generally sparse, much soil is exposed. Buffalo grass is typical of the American steppe; other typical plants are the sunflower and locoweed.

The semidesert cover is a xerophytic (plants that are structurally adapted for life and growth with a limited water supply) shrub vegetation accompanied by a poorly developed herbaceous layer. Trees are generally absent. An example of semidesert cover is the sagebrush vegetation of the middle and southern Rocky Mountain region and the Colorado Plateau. On the Colorado Plateau there is pinyon-juniper woodland. On the eastern side of Texas, the grasslands grade into either savanna woodland or semideserts, which are composed of xerophytic shrubs and trees. The climate becomes semiarid-subtropical allowing for the presence of cactus plants.

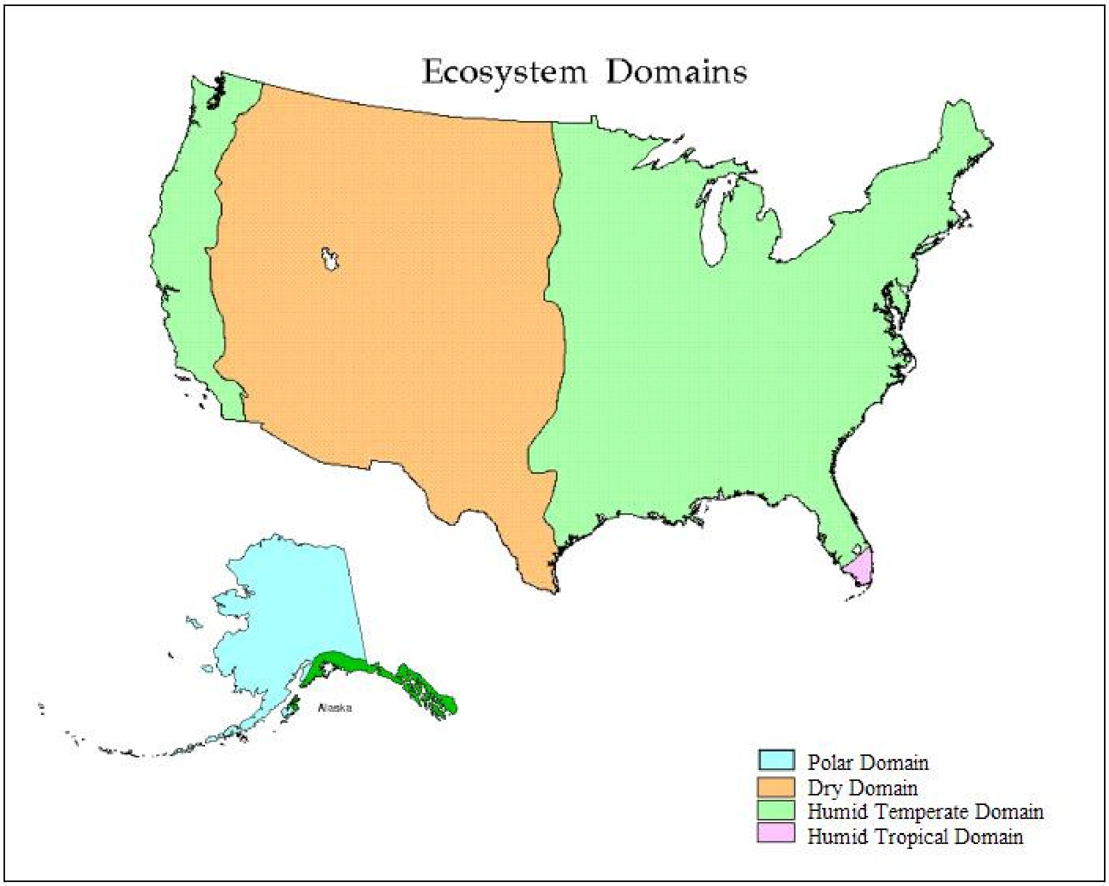

Figure 3-26. Ecological Domains of the Continental United States

3.5.1.3 Humid Tropical Domain

The humid tropical domain is restricted to the southern end of Florida. The climate is largely controlled by equatorial and tropical air masses. The average temperature for each month of the year is above 64°F (18°C) and there is no distinctive winter season. Average annual rainfall is heavy and exceeds annual evaporation.

Alternating wet and dry seasons result in the growth of distinctive vegetation known generally as tropical savanna, characterized by open expanses of tall grasses interspersed with hardy, drought-resistant shrubs and trees. Some areas have savanna woodland, monsoon forest, thornbush, and tropical scrub. In the dry season, grasses wither into straw and many tree species shed their leaves. Other trees and shrubs have thorns and small or hard leathery leaves that resist loss of water.

3.5.1.4 Polar Domain

Located at high latitudes of Alaska, the climate in the polar domain is controlled chiefly by polar and arctic air masses which are characterized by low temperatures, severe winters, and small amounts of precipitation, most of which fall in the summer months. In the northern part of Alaska the tundra is characterized by grasses, sedges, lichens, and willow shrubs. Moving southward, the vegetation changes into birch-lichen woodland, and then into needleleaf forest. In some places, a distinct tree line separates forest from tundra. South of the tundra, the sub-arctic climate zone coincides with a great belt of needleleaf forest, often referred to as boreal forest, and with the open lichen woodland known as taiga where most trees are small and therefore are valued more as pulpwood rather than lumber.

3.5.2 Wildlife

The distribution of wildlife in the U.S. is dependant, to a large extent, on the climate of the different ecoregions. The following paragraphs summarize the types of wildlife in each of the four ecological domains (USFS, 2004).

3.5.2.1 Humid Temperate Domain

Wildlife in this domain is quite varied. Some of the more important mammals include the whitetail deer, black bear, bobcat, gray fox, raccoon, gray squirrel, fox squirrel, and eastern chipmunk. The black bear occurs quite commonly in the Appalachians and surrounding areas. Whitetail deer are very common. The mink and river otter are indicative of the riverine forests primarily in the northern Midwest region of the country.

3.5.2.2 Dry Domain

This domain is home to many large mammals, some of the more common ones include elk, dear, bighorn sheep, mountain lion, bobcat, and black bear. Grizzly bear and moose inhabit the northern portions of this domain. Mule deer and whitetail deer are common, especially where brush cover is available along stream courses. Sagebrush shrub lands provide habitat for pronghorn antelope and whitetail prairie dog. Beaver and muskrat inhabit many of the lakes and streams.

3.5.2.3 Humid Tropical Domain

Common mammals indicative of this domain include whitetail deer, Florida panther, black bear, raccoon, bobcat, opossum, skunk, various bats, marsh and swamp rabbits, cotton rat, and fox squirrel. Manatees inhabit estuaries and interlacing channels.

3.5.2.4 Polar Domain

The upland and coastal areas of this domain supports a variety of wildlife, such as brown and black bear, wolf, wolverine, coyote, caribou, reindeer, snowshoe hare, red fox, lynx, beaver, moose, squirrels, mice, weasel, mink, and marten. Along the northern Bering Sea coast, polar bear, walrus, and arctic fox are occasionally found.

The Brooks Range is an important big-game area in Alaska, supporting brown and black bear, wolf, wolverine, caribou, and Dall sheep. Smaller mammals include marmot, red and arctic fox, ground squirrel, lemming, and pika.

The spruce-hardwood forests found in this domain provide excellent habitat for furbearers and other mammals. Brush zones and immature forests recovering from fires furnish especially good browse for moose. Common game animals in addition to moose include black and brown bear, wolf, wolverine, and caribou. Smaller mammals include lynx, red fox, beaver, mink, muskrat, weasel, river otter, marten, red and northern flying squirrel, and deer mouse.

3.5.3 Aquatic Habitat

The continental U.S., including Alaska contains a large variety of aquatic habitats, which in turn support a wide diversity of aquatic biota. There are 3.5 million miles of streams (approximately two thirds perennial), 41 million acres of lakes and reservoirs, 34,400 square miles of estuaries (excluding Alaska) in the U.S. (Loftus and Flather, 2000). The 191 million acres of National Forest System lands contain 128,000 miles of fishable streams and rivers, over 2.2 million acres of lakes, ponds and reservoirs, and 12,500 miles of coast and shoreline (Maharaj and Carpenter, 1999). The BLM manages over 168,000 miles of streams and more than 2.5 million acres of lakes and reservoirs (Sport Fishing Institute, 1993). Other federal agencies manage lesser amounts of waters. In terms of water quality, 70 percent of the nation's assessed river miles, lake acres, and estuarine area (in square miles) can support the "aquatic life use" designated under the Clean Water Act (EPA, 1996).

There are approximately 800 freshwater fish species in the U.S. (SAMAB, 1996). Habitats include small desert springs in the southwest that support unique and endemic fish species such as the desert pupfish; the blue ribbon trout waters of the Colorado, Green, and Snake Rivers; the salmon rivers of California, Oregon, and Washington, as well as thousands of lakes and reservoirs.

Sport fish throughout the U.S. include a variety of species, such as trout, salmon, catfish, sunfish, including various species of bass, suckers, perch, walleye, and pike. Non-sport fish include numerous species of minnows, shiners, dace, and other species. In addition to the fish, the aquatic habitats also support a tremendous variety of aquatic invertebrates, including mollusks, crustaceans, and insects.

3.5.3.1 Wetlands

Wetlands are considered to be a valuable ecological resource because of their important role in providing fish and wildlife habitat, maintaining water quality and flood control. In the past, wetlands were considered low value land that impeded commercial land development. It wasn't until relatively recent that the true value of wetlands was understood. Characteristics and functions of wetlands (Kusler, 1983) include:

- Isolated Wetlands
    - Waterfowl feeding and nesting habitat
    - Habitat for both upland and wetland species of wildlife
    - Floodwater retention area
    - Sediment and nutrient retention area
    - Area of special scenic beauty
- Lake Margin Wetlands
    - Those listed for "isolated wetlands"
    - Removal of sediment and nutrients from inflowing waters
    - Fish spawning area

- Riverine Wetlands
    - Those listed for “isolated wetlands”
    - Sediment control, stabilization of river banks
    - Flood conveyance area
- Estuarine and Coastal Wetlands
    - Those listed for “isolated wetlands”
    - Fish and shellfish habitat and spawning areas
    - Nutrient source for marine fisheries
    - Protection from erosion and storm surges
- Barrier Island Wetlands
    - Habitat for dune-associated plant and animal species
    - Protection of backlying lands from high-energy waves
    - Scenic beauty

The total wetland area present in the Continental U.S. is 274,000,000 acres (112,000,000 ha), which represents approximately 12 percent of the total surface area (Dahl, 1990). Wetlands throughout the U.S. have experienced a major decline in abundance because of human disturbance. From the 1780s to the 1980s, 53 percent of the total acreage of wetlands in the continental U.S., excluding Alaska, has been lost (Dahl, 1990). Wetland area and historic losses for each state are listed in Table 3-8.

Table 3-8. Wetlands by State

State	Wetland Area	Percent of Surface Area	Wetland Loss (%) 1780s to 1980s
Alabama	3,783,800	11.5	50
Alaska	170,000,000	45.3	50
Arizona	600,000	<1	36
Arkansas	2,763,600	8.1	72
California	454,000	<1	91
Colorado	1,000,000	1.5	50
Connecticut	172,500	5.4	50
Delaware	223,000	16.9	54
Florida	11,038,300	29.5	46
Georgia	5,298,200	14.1	23
Hawaii	51,800	1.3	12
Idaho	385,700	<1	56
Illinois	1,254,500	3.5	85
Indiana	750,633	3.2	56
Iowa	421,900	1.2	89
Kansas	435,400	0.8	48
Kentucky	300,000	1.2	81
Louisiana	8,784,200	28.3	46

State	Wetland Area	Percent of Surface Area	Wetland Loss (%) 1780s to 1980s
Maine	5,199,200	24.5	20
Maryland	440,000	6.5	73
Massachusetts	588,486	11.1	28
Michigan	5,583,400	15	50
Minnesota	8,700,000	16.2	42
Mississippi	4,067,000	13.3	59
Missouri	5,583,400	1.4	50
Montana	840,298	<1	27
Nebraska	1,905,500	3.9	35
Nevada	236,349	<1	52
New Hampshire	200,000	3.4	9
New Jersey	915,960	18.3	39
New Mexico	481,900	<1	33
New York	1,025,000	3.2	60
North Carolina	5,689,500	16.9	49
North Dakota	2,490,000	5.5	49
Ohio	482,800	1.8	90
Oklahoma	949,700	2.1	67
Oregon	1,393,875	2.2	38
Pennsylvania	499,014	1.7	56
Rhode Island	65,154	8.4	37
South Carolina	4,659,000	23.4	27
South Dakota	1,780,000	3.6	35
Tennessee	787,000	2.9	59
Texas	7,612,412	4.4	52
Utah	558,000	1.0	30
Vermont	220,000	3.6	35
Virginia	1,074,613	4.1	42
Washington	938,000	2.2	31
West Virginia	102,000	<1	24
Wisconsin	5,331,392	14.8	46
Wyoming	1,250,000	2.0	38

Source: Dahl, 1990.

3.5.4 Threatened and Endangered Species

Animals, birds, fish, plants, or other living organisms in jeopardy of extinction by human-produced or natural changes in their environment are considered threatened or endangered. Requirements for declaring species threatened or endangered are contained in the 1973 Endangered Species Act (ESA). This Act protects animal and plant species currently in danger of extinction (endangered) and those that may become endangered in the foreseeable future (threatened). The Act provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through federal action and by encouraging the establishment of state programs. Section 7 of this act requires federal agencies to ensure that all federally associated activities within the U.S. do not harm the continued existence of threatened or endangered species or designated areas (critical habitats) important in conserving those species.

3.5.4.1 Federally Listed Species

The ESA was passed in 1973 to address the decline of fish, wildlife, and plant species in the U.S. and throughout the world. The purpose of the ESA is to conserve "the ecosystems upon which endangered and threatened species depend" and to conserve and recover listed species (ESA, 1973; Section 2). The law is administered by the U.S Fish and Wildlife Service (USFWS) and the Commerce Department's National Marine Fisheries Service (NMFS). The USFWS has primary responsibility for terrestrial and freshwater organisms, while the NMFS is primarily responsible for marine species such as salmon and whales.

Under the law, species may be listed as either "endangered" or "threatened." The ESA defines an endangered species as any species that is in danger of extinction throughout all or a significant portion of its range (ESA, 1973; Section 3(6)). A threatened species is one that is likely to become an endangered species within the foreseeable future throughout all or a significant part of its range (ESA, 1973; Section 3(20)). All species of plants and animals, except pest insects, are eligible for listing as endangered or threatened. The ESA also affords protection of "critical habitat" for threatened and endangered species. Critical habitat is defined as the specific areas within the geographical area occupied by the species at the time it is listed, on which are found physical or biological features essential to the conservation of the species and which may require special management considerations or protection (ESA, 1973; Section 3(5)(A and B)). Except when designated by the Secretary of the Interior, critical habitat does not include the entire geographical area that can be occupied by the threatened or endangered species (ESA, 1973; Section 3(5)(C)).

Some species may also be candidates for listing (ESA, 1973; Section 6(d)(1) and Section 4(b)(3)). The USFWS defines proposed species as any species that is proposed in the Federal Register to be listed under Section 4 of the ESA; while candidate species are those for which the USFWS has sufficient information on their biological status and threats to propose them for listing as endangered or threatened under the ESA, but for which development of a listing regulation is precluded by other higher priority listing activities (USFWS, 2004a). The NMFS defines candidate species as those proposed for listing as either threatened or endangered or whose status is of concern, but for which more information is needed before they can be proposed for listing. Candidate species receive no statutory protection under the ESA, but by definition these species may warrant future protection under the ESA. Currently, 1,265 plant and animal species are listed as either threatened or endangered under the ESA (USFWS, 2004b).

3.5.4.2 State Listed Species

Each state has species that are identified as protected. There is great variation in the state programs for protection of species of concern. Some species are listed per a specific definition and afforded protection and/or management under a state regulation. Other species may be included on a watch list. The distribution and abundance of these species may be tracked by organizations, such as the state Natural Heritage Program. State protected species that may be affected by a specific carbon sequestration project would depend upon the location of that particular project, and will be addressed in site-specific environmental analyses.

Table 3-9 presents the number of endangered and threatened species in the U.S. and species with designated critical habitat. A total of 518 animals and 746 plants are currently protected by the ESA. Critical habitat has been designated for 162 animals and 310 plants. In addition, there are 135 animal and 143 plants that are candidates for protection under the ESA (USFWS, 2004a).

The USFWS designated the bald eagle (*Haliaeetus leucocephalus*) as threatened on March 11, 1967. The current range of the bald eagle includes all of the conterminous U.S. and Alaska. The bald eagle is especially common in areas with large expanses of aquatic habitat, including Florida, Maine, the Chesapeake Bay, the Great Lakes and lake regions located in northern California, Oregon, Washington, and Alaska. The bald eagle is still susceptible to a number of threats, particularly environmental contaminants and excessive disturbance by humans (Buehler, 2000).

Table 3-9. Number of Endangered and Threatened Species in the U.S.

Taxonomic Group	Endangered	Threatened	Total Species	Species with Critical Habitat
Mammals	69	9	78	18
Birds	77	13	90	20
Reptiles	14	22	36	15
Amphibians	11	10	21	5
Fish	71	43	114	58
Clams	62	8	70	18
Snails	21	11	32	2
Insects	35	9	44	12
Arachnids	12	0	12	6
Crustaceans	18	3	21	8
Animal Subtotal	390	128	518	162
Flowering Plants	571	144	715	298
Conifers and Cycads	2	1	3	0
Ferns and Allies	24	2	26	12
Lichens	2	0	2	0
Plant Subtotal	599	147	746	310
Total	989	275	1264	472

** As designated in the Code of Federal Regulations (50CFR Part 17.95 and 17.96 and 226). As of November 22, 2004.*

Source: USFWS, 2004a.

3.6 CULTURAL RESOURCES

This section describes cultural resources that may be affected by carbon sequestration projects. For the purposes of this section, cultural resources generally include paleontological, archaeological and historic resources. This section provides information on the definition of cultural resources; relevant federal laws and regulatory requirements; DOE directives, policies and guidance; a summary of the national context; a summary of each regional context; and a summary of Native American population.

3.6.1 Definition of Cultural Resources

Cultural resources include prehistoric and historic districts, sites, structures, artifacts, and any other physical evidence of human activities considered important to a culture, subculture, or community, for scientific, traditional, religious, or other reasons. Cultural resources can be divided into three major categories: prehistoric and historic archaeological resources, historic buildings and structures, and traditional cultural properties. Paleontological resources are also considered under NEPA.

Cultural resources are defined as historic properties covered by the National Historic Preservation Act (NHPA); as cultural items covered by the Native American Graves Protection and Repatriation Act (NAGPRA); as archaeological resources covered by the Archeological and Historic Preservation Act (ARPA); as sacred sites (to which access is provided) under the American Indian Religious Freedom Act (AIRFA) in Executive Order 13007; as collections and associated records covered by 36 CFR Part 79, Curation of Federally Owned and Administered Collections; and as paleontological specimens (i.e., fossils) covered by the Antiquities Act and, if found in association with archeological resources, by ARPA. A summary of cultural resource terms in provided in Table 3-10.

Table 3-10. Cultural Resources Terms

Prehistoric and Historic Resources. These resources are locations where human activity measurably altered the earth or left deposits of physical remains (e.g., arrowheads or pottery). Prehistoric resources are physical properties that remain from human activities that predate written records; they range from scatterings of a few artifacts to village sites and rock art that predate written records in a region. Historic archaeological resources include remains of structures, roads, fences, trails, dumps, battlegrounds, mines, and a variety of other features. Historic resources consist of physical properties that postdate the existence of written records. In the U.S., historic resources are generally considered to be those that date no earlier than 1492.

Historic Properties. Historic properties can include buildings, sites, structures, objects, and districts. Properties considered significant are usually 50 years old or older. There are exceptions, however, such as, properties that meet significance criteria.

Historic Buildings and Structures. These include standing buildings, dams, canals, bridges, and other structures of historic or aesthetic significance. In general, architectural resources must be more than 50 years old to be considered for protection under laws protecting cultural resources.

Traditional Cultural Properties. These resources can include archaeological resources, buildings, neighborhoods, prominent topographic features, habitats, plants, animals, and minerals that Native Americans or other ethnic groups consider essential for the preservation of their traditional culture. Native American resources are sites, areas, and materials important to Native Americans for religious or heritage reasons. In addition, cultural values are placed on natural resources such as plants, which have multiple purposes within various Native American groups.

Paleontological Resources. Paleontological resources are scientifically significant physical remains, impressions, or traces, fossilized remains, specimens, deposits, and other such data from prehistoric nonhuman life, including remains of plants and animals.

(Sources: National Historic Preservation Act, Native American Graves Protection and Repatriation Act, Archeological and Historic Preservation Act, American Indian Religious Freedom Act, 36 CFR Part 79, and Antiquities Act)

3.6.2 National Context

The context of cultural resources is generally viewed in terms of the interaction over time of plants, animals, and humans with their environment. While there is evidence of abundant plant and animal life in North America going back millions of years, the composition and distribution of these plants and animals changed over long periods of time. For example, dinosaurs emerged more than 200 million years ago, were dominant for 70 million years, and around 65 million years ago became extinct along with half of all plant and animal life on earth. The fossils of dinosaurs and millions of other animals and plants have been found, including sponges, snails, shellfish, turtles, beetles, bears, worms, leaves, trees, and on and on. Based on the age of the oldest known fossils, it seems that human life began about 2.5 million years ago. *Homo* *sapiens sapiens* (fully modern man) evolved around 35,000 years ago, and then as part of a general expansion spread throughout the world. It is believed that only anatomically modern humans settled in the Americas.

The settlement of North America by modern humans may have been facilitated by climate change. There were periods where cooling (glaciation) and warming (interglacial) alternated regularly; this was caused by the changing shape of the earth's orbit, tilting of the earth's axis, and shifting times when the earth was closest to the sun (precession of the equinoxes). During several periods of climatic cooling, the Bering Strait land bridge (or Beringia) was exposed. Periods of climatic cooling include the period from 75,000 to 45,000 years ago; a lengthy period of less cold climate from about 40,000 to 25,000 years ago; and a bitterly cold period from 25,000 to around 14,000 years ago. It is believed that during these periods human migration was possible on land from Asia to North America. It is speculated that other migratory routes, such as coastal/maritime, also were possible. While research continues, the earliest secure settlement of Homo sapiens sapiens in North America was about 14,000-12,000 years ago.

3.6.2.1 Prehistoric Period Resources

Prehistoric human occupation in the U.S. is divided generally into three major periods depending on region: the Paleo-Indian Period, the Archaic Period, and, in the East and Midwest, the Woodland Period; in the West, the Formative Period, or the Fremont Period, and the Late Prehistoric Period; and in the South, the Woodland and Mississippian Periods. The most recent periods vary significantly, with each region and state defining different periods and dates. Archaeological remains or sites from each of the periods discussed below might be found, depending on topography (e.g., degree of slope, distance from fresh water) and amount of soil disturbance due to natural (e.g., erosion) or cultural (e.g., construction, agriculture, forestry, or Agency tasks) activities.

Paleo-Indian Period (ca. 12,000 B.C. to ca. [varies regionally] B.C.). The Paleo-Indian Period is the earliest evidence of humans in the New World. The climate during this time period was cooler than the present environment. Large animals, such as mammoth and extinct species of bison, flourished. Paleo-Indian peoples were nomadic hunters and gatherers who lived in small groups and ate wild plants and animals. This period is distinguished by a low population density with groups residing in seasonal or base camps; as a result, Paleo-Indian sites are rare and usually very small in size. The Paleo-Indian Period is also noted for diagnostic fluted projectile points and the exploitation of Pleistocene megafauna, such as mammoths and giant sloth.

Archaic Period (varies regionally). Archaeologists divide the Archaic Period into three time frames—Early, Middle, and Late. Between 10,000 years before the present (BP) and 5,000 BP, substantial climatic and ecological changes occurred across the North American continent. During the Archaic Period, the cold dry environment that had existed during the Paleo-Indian Period changed to a warmer and wetter environment. These changes were accompanied by a change from Paleo-Indian to Archaic traditions. Groups responded to these changes, and archaeological evidence shows increased use of the new environment. These groups lived a nomadic life, moving seasonally to make use of the variety of flora and fauna available in different locations or ecological zones at different times of the year. Mammals included mountain sheep, deer, and smaller mammals and birds. Milling stones and items made of wood, bark, and fiber are common during this Period. During the Late Archaic Period, the ecology and climate became much the same as they are today, with a higher sea level and wetter climate than those of the previous period.

Woodland Period (varies regionally). This period is identified in the Mid-Atlantic, Northeast, Southeast, and Midwest. It is divided into three periods—the Early Woodland, the Middle Woodland, and the Late Woodland. The Woodland Period is characterized by the first appearance of true-fired ceramics. Food storage pits provide archaeological evidence that the population became more sedentary during this period, and plant remains indicate that plants were domesticated during this period.

Mississippian Period (varies regionally). This period is identified in the Southeast by the presence of certain ceramic types and stone tools, large-scale earthworks, and the remains of villages.

Late Prehistoric Period (varies regionally). This period is identified by archaeologists in the Southwest, particularly Texas and Colorado. During this period, people changed from somewhat egalitarian, nomadic hunter-gatherers relying on wild plants and animals to people who practiced agriculture and lived in more hierarchical chiefdom societies. Agricultural remains include maize; other remains include ceramic pottery, storage pits, hearths, and small triangular projectile points.

Formative Stage and Post-Formative Stage (varies regionally). These stages are identified in some areas of the West. During the Formative Stage, agriculture was introduced into the region. Groups became more sedentary, living longer in one location. They lived in small villages, and remains of their pit houses and masonry structures can be identified archaeologically. These stages are characterized archaeologically by the presence of ground stone artifacts, used for processing food; specific ceramic types; and remains of structures, including pit houses. During the Post-Formative Stage, historically known Native American groups lived in the West.

Fremont Period (varies regionally). This period is recognized in Colorado and in the Great Basin. It is largely defined by farming (i.e., squash, sunflower, beans, and maize) but also included full- and part-time farmers and foragers, depending on location and season. The Period is also known for the appearance of semisubterranean structures and storage pits, and aboveground granaries.

3.6.2.2 Historic Period Resources

3.6.2.2.1 Contact Period

Historic Native Americans lived throughout the U.S. during the period from 1492 (landfall of Columbus) onward. Contact between the different cultures (European, African, and Native American) varied from region to region. The earliest contacts were along the eastern and western coasts, where the Spanish first landed.

In the Southeast, first contact was made when Hernando de Soto and his men explored that area between 1540 and 1542. They traveled from present-day Tampa Bay through Florida, Georgia, Tennessee, Alabama, Mississippi, and Arkansas, encountering Mississippian peoples.

The interior parts of the country did not experience contact until centuries later; in the West, earliest contact among Native American groups and people of European and African descent was made by Lewis and Clark (1804-1806), as well as by French and English fur trappers and French Catholic missionaries (for example, in the upper Midwest and Northwest). Native American groups experienced extreme population decline and dislocation during this period, as a result of warfare and disease. The Contact Period ends at different times in different regions. Contact Period cultural resources can include archaeological sites, objects, and standing structures or remains of structures.

3.6.2.2.2 Historic Period

The start of this period varies from region to region, and the period continues until the present time. Each state has a set of historic contexts, such as homesteading era, railroading era, rural agricultural era, on World War II era. Each of these has been defined by the SHPO and is used as a context for evaluating the NRHP eligibility and significance of archaeological sites, objects, and standing structures. Historic Period sites can include archaeological sites, objects, standing structures or remains of structures, roads, or railroad tracks. In most cases, the resource must be at least 50 years old; however, some exceptions, such as structures or scientific equipment considered significant might be NRHP-eligible.

3.6.3 Regional Context

At time of contact with European culture, there were a great variety of Native American groups in North America. For example, linguists believe that at least 200 languages were spoken in North America. In light of this complex situation, a number of ways have been devised to organize and analyze North American Native American cultural resources. These consider factors such as geography, environment, language, population density, religion, shelter, transportation, subsistence patterns, and sociopolitical organization. The most common approach divides U.S into 8 regional cultural areas (Waldman, Atlas of the North American Indian, 2000):

- Northeast: Includes northeastern states as far west and south as eastern Minnesota, western Illinois, eastern Missouri, northern Tennessee and northern Virginia.
- Southeast: Includes Virginia, North Carolina, South Carolina, Georgia, Florida, Tennessee, Alabama, Mississippi, southern Arkansas and eastern Texas.
- Southwest: Includes southern New Mexico, western Texas, and southern Arizona.
- Great Basin: Includes western Colorado, Utah, southern Idaho, southeastern Oregon, Nevada, northern Arizona and northern New Mexico.
- California: coastal California
- Northwest Coast: western Washington, western Oregon, northern California.
- Arctic and Subartic: Alaska.
- Plateau: Includes northern Idaho, eastern Washington, and eastern Oregon.
- Great Plains: Includes western Minnesota, Iowa, western Missouri, Arkansas, Oklahoma, central Texas, Kansas, Nebraska, South Dakota, North Dakota, Montana, eastern Wyoming, and eastern Colorado.

These areas generally represent patterns of Native American life just before contact with European culture. Two factors, however, should be noted. First, while they are useful as a general analytical approach, they should not be taken to imply an internal cultural homogeneity within each area.

3.6.3.1 Northeast Cultural Area

This area loosely comprises the area from New England to the western Illinois border (plus most of Wisconsin, the northeast corner of Minnesota, a wedge in middle Tennessee, all of coastal Virginia, and the northern half of coastal North Carolina). Despite the physiographic diversity of the Northeast cultural area, the forest, both deciduous and coniferous, is the one constant. The Northeast tribes at the time of contact were inheritors of earlier traditions, sometimes grouped together as “Woodland.” Tribes or groups were small and widely scattered in small bands.

The principal language families in the Northeast Cultural Area were the Algonquians and Iroquois. It is thought that the Iroquoian tribes were more recent arrivals in the region than the Algonquians and that they probably migrated from the south. Both the Iroquoian and Algonquians had strong tribal identities that went beyond the basic nuclear family. Major Native American tribes in the Iroquoian language family located included the Susquehannock while those in the Algonquian language family included the Nantocoke, Potawatomi and Menominee. The Iroquoians generally lived in communal longhouses while the Algonquians generally lived in smaller wigwams with longhouses serving as council or ceremonial buildings. The Iroquoian subsistence pattern was highly dependent on vegetable farming with the three main source of food being maize, beans and squashes.

3.6.3.2 Southeast Cultural Area.

Most Native Americans of the Southeastern cultural area made their homes in villages along river valleys. Because of the common sandy soil conditions, agricultural fields and the corresponding village site frequently changed. Cultivated corn, beans, squash, sunflowers and gourds were the major source of food, except in south Florida. Fish were plentiful, and in some areas, such as along the lower Mississippi River, fish and water fowl provided at least half the protein of the Indian's diet. The main type of architecture involved branches and vines tied over pole and frameworks, then covered with a mixture of mud plaster.

Despite similarities in lifeways throughout the area, there were many different language families at the time of European contact. These included the Muskogean, Siouan, Iroquoian, Caddoan, Timucuan and Tunican. Some people, like the Natchez, are considered direct descendants of the ancient temple mound builders of the Mississippian culture, but others were later arrivals who inhabited many of the same sites. The Southeast cultural area contained complex societies where chiefdoms were centered on a capital town containing massive earthworks in the form of mounds. For example, Moundville was a chiefdom (located about 60 miles from present day Birmingham, AL) on the northeastern edge of the Muskogee territory; within its 300 acres were 20 major mounds of roughly pyramidal shape, the largest of which was 60 feet in height.

The Southeast chiefdoms were expansive, fighting with their neighbors. Everyone with a chiefdom belonged to a clan, each associated with a tutelary spirit. The clans were matrilineal, exogamous (i.e., marriage within the clan was prohibited), and every clan spread through many villages. Chiefly office and lesser ranks were hereditary. In traditional Southeastern cultures, there were no sharp distinction between religious and medical beliefs, rituals and practices.

3.6.3.3 Southwest Cultural Area

The Southwest cultural area (sometimes characterized as Las Vegas, NV-to-Las Vegas, NM, and Durango, CO-to-Durango, Mexico) is described as an arid area with an annual average rainfall ranging from less than 20 inches to less than 4 inches. Within this area, two predominant Native American lifestyles—agrarian and nomadic—developed. The agrarian peoples included Pueblo Indians of the Rio Grande, upland and river Yuman-speakers, and the Uto-Aztecan-speaking Pima and Papago. These people were politically independent, and socially and economically self-sufficient. In fact, agriculture north of Mesoamerica reached its highest level of development in the southwest. These skilled farmers could support sizable populations in permanent villages that the Spanish termed earthen pueblos. Each Pueblo culture was a village that functioned as an autonomous political entity. The family was the cornerstone of life, religion transcended and permeated all aspects of life, and they developed an extensive native literature expressed through song, folk stories and oratory. In contrast to the agricultural basis of Pueblo life, the Athapascan Apache and Navajo, later arrivals to the region from the north, were nomadic hunters and gatherers. They supplemented their diet by raiding Pueblo and other villages for their crops. Most of the Apaches lived in small units based on extended families; local groups composed of several matri-focal extended families formed bands, the largest level of political organization. The two main types of housing were brush-covered wickiups and earth-covered hogans.

3.6.3.4 Great Basin Cultural Area

The Great Basin cultural area generally is surrounded by uplands; to the east are the Rocky Mountains, to the west are the Sierra Nevada, to the south is the Colorado Plateau, and to the north is the Columbia Plateau. The rivers and streams of the Great Basin drain from these flanking uplands into the central depression without any outlet to the ocean. Rainfall is this area is low and evaporation high. Because of the area's unique geology, waters tend to be saline. The tribes of the Great Basin were of one language family, the Uto-Aztecan. The major Native American groupings from the Great Basin cultural area included Ute and Southern Paiute. Because of meager food supplies, their major food resources were roots and seeds. People generally traveled in small family groups with minimal tribal identity and few community rites. During the spring and summer, housing consisted of temporary shelters or windbreaks made of reed mats and branches; during the winter, shelters were more substantial, some being subterranean with an opening through the mound-like roof that served as both a door and smokehole.

3.6.3.5 California Cultural Area

The California cultural area contained bountiful flora and fauna. Because of ample food sources, the California region supported the densest population north of Mescoamerica without the practice of agriculture. The basic social unit was the family with groups of families forming villages presided over by a single chief. There was a high degree of isolation among these villages with little movement of people once the group was established. At the time of European contact, more than 100 distinct dialects were spoken by native peoples. These included language families of the Hokan phylum (viz., a large division of related families of languages or linguistic stocks) in the north and coastal-central; the Penutian phylum in the north-central and north; and the Uto-Aztecan phylum in the south.

3.6.3.6 Northwest Coast Cultural Area

The Northwest Coast cultural area's temperate climate and abundant rainfall nourished a lush evergreen forested area. The forests, rivers and ocean offered plentiful fish and game. With this food source, the Native Americans of this area supported a dense population along the coast and had sufficient time to develop an affluent and high complex society. There were no large political units outside of the individual village. Villages typically were sited on narrow sand and gravel beaches of the mainland and islands or along inland rivers; houses faced the water. Totem poles were prevalent along the lower Tlingit, Haida, Tsimishian and Kwakiutl peoples. Large extended families often lived together in communal longhouses. Family ties were extremely important with people identifying closely with extended families and lineages. Among the Tlingit, Haida and Tsimishian in the Alaska panhandle, society was matrilineal, while among the Salish groups in British Columbia and Washington, inheritance came from both parents. Ceremonial gatherings, called potlatches, were important for validating tribal rank, leadership, and cultural heritage. The language families and isolates (viz., languages not related to others) were represented by two major phyla: Na-Dene (spoken by the Tlingit and Haida as well as a number of Athapascan peoples) and Penutian (spoken by such tribes as Chinook, Kalapuya, Siuslaw, Coos and Takelma).

3.6.3.7 Subartic Cultural Area

The Subartic cultural area contained scattered and few aboriginal people who had to cope with long, harsh winters as well as short summer plagued with black flies and mosquitoes. Most Subarctic peoples were nomadic hunter-gathers. They survived without agriculture, and traveled in small bands united by kinship and a common dialect. Tribal cohesion tended to be minimal; only for comparatively short periods during the summer months did these various groups rendezvous and express a form of tribal solidarity. Up to a point, emphasis was placed on personal autonomy, especially self-reliance and personal initiative. Athapascans made up the main language group in the western Subartic cultural area; these peoples lived near and were influenced by the Inuit. Subarctic Native American tribes located principally in the interior of Alaska included the Holikachuk, Ingalik, Kolchan, Tanaina, Koyukon, Tanana and Ahtna.

3.6.3.8 Artic Cultural Area

The Arctic cultural area was peopled by migrants from Siberia who came relatively late to North America, probably from 2500 to 1000 B.C. They did not travel the Bering Strait land bridge, but came by boat or by riding ice flows. As they spread across the north, three linguist groups evolved. First, the

Aleut separated from the Eskimo-Aleut stock and then the Yup'ik and Inuit-Inupiaq split. The primary means of subsistence was hunting, especially sea mammals and caribou, supplemented by fishing. They exhibited a uniformity of culture, and there was only one defined language (Eskimaleut). The cultural grouping included South, West and North Alaskan Inuit; Aleut; Saint Lawrence Island Inuit; and Mackenzie Inuit.

3.6.3.9 Plateau Cultural Area

The Plateau cultural area is flanked by the Cascades Mountains on the west, the Rocky Mountains on the east, the desert country of the Great Basin on the south, and the forest and hill country of the upper Fraser River on the north. Through fishing, hunting and gathering, the Native Americans of this region could subsist without farming. Habitations varied in style and emphasis. Villages were the main political units. The acquisition of horses, probably around the first quarter of the 18^{th} century, resulting in increased interaction with more distant tribes such as those on the Plains to the east. North of the Columbia River, the most common language family was Salishan (of uncertain phylum), with dialects spoken by tribes such as Coeur d'Alene, Flathead and Kalispel. Language families and isolates of the Penutian phylum were spoken in the south by tribes such as the Nez Perce.

3.6.3.10 Great Plains Cultural Area

This is a vast region of predominantly treeless grassland. The eastern prairies receive 20-40 inches of rainfall a year, resulting in long grass while the western high plains have 1-20 inches of rainfall and short grass. At the time of contact with European culture, most of the region's tribes were villagers and farmers, or at least semi-nomads. Early agriculturalists included the Siouan-speaking Manadan and Hidatsa, and the Caddoan-speaking Wichita and Pawnee. Other peoples entered the region at later dates because of unfavorable conditions elsewhere or to pursue buffalo herds; these included Algonquian-speaking Arapaho and Cheyenne from the northeast; the Siouan-speaking Sioux (Dakota, Lakota and Nakota), Ponca, Ioway, Omaha, Otoe, Kaw (Kansa), Missouria and Osage from the east; the Kiowa-Tanoan-speaking Kiowa from the northwest; and the Athapascan-speaking Kiowa-Apache from the southwest.

This cultural area is unique in that the typical Native American subsistence pattern and related lifeways evolved after contact with European culture. In fact, full flowering of the historic Plains culture did not occur until the acquisition of the horse from the south and the gun from the east. For example, the reintroduction of horses by the Spanish allowed for increased mobility and prowess. As a result, the former village and farming tribes of river valleys became nomadic hunters, especially of the buffalo. Bands of related families made up the Great Plains tribes. The bands lived apart most of the year, but came together for communal buffalo hunts and ceremonies in the summer. A complex intertribal trade network developed between these nomadic hunters and more sedimentary peoples. The typical dwelling was a portable cone-shaped tipee with pole frameworks covered with buffalo hides. The tipee was generally pitched with its back toward the prevailing westerly wind direction, its wide base and sloping side giving a high degree of stability.

3.6.4 American Indian Population

There are no precise figures on how many American Indians were in North America at the time of first contact with European culture. The estimate most often used for the region north of Mexico is 1 million (750,000 for what is now the U.S. and 250,000 for Canada) to 1 and 1.5 million. After European contact, not only did the patterns of American Indian population density begin to change, but the numbers declined to a low of less than 250,000 between 1890 and 1910. Since then, the American Indian population has rebounded. According to the 2000 U.S. Census, there are 2,475,956 Indians, Eskimos or Aleuts in the U.S. (0.9 percent of the total U.S. population of 281,421,906); of these, only 479,390

Indians (less than 0.2 percent of the total U.S. population) live on 314 federally recognized reservations in the U.S.

Maps of federally recognized Indian tribes and American Indian populations in the U.S. can be accessed at http://www.census.gov/geo/www/maps/aian_wall_map/aian_wall_map.htm.

The 2000 population by state of Americans Indians who live on reservations is summarized in the following Table 3-11, while Table 3-12 shows American Indian population by reservation in each applicable region. The tables show statistics only for "Indian land" classified as a reservation, pueblo, rancheria, colony, or community.

Table 3-11. Population Statistics for American Indian Reservation by State

American Indian Reservation and Off-Reservation Trust Land (Federal)	American Indian or Alaska Native
Alabama	131
Alaska	156,776
Arizona	161,284
California	15,684
Colorado	12,191
Connecticut	227
Florida	1,239
Idaho	7,306
Iowa	632
Kansas	1,358
Louisiana	822
Maine	2,005
Massachusetts	66
Michigan	5,347
Minnesota	17,171
Mississippi	4,902
Montana	22,787
Nebraska	4,343
Nevada	7,039
New Mexico	104,813
New York	7,349
North Carolina	6,665
North Dakota	18,733
Oklahoma	238,331
Oregon	5,011
Rhode Island	9
South Carolina	362
South Dakota	41,712
Texas	1,310
Utah	9,623
Washington	27,150
Wisconsin	15,557
Wyoming	6,544
TOTAL	904,479

Source: 2000 U.S. Census.

Table 3-12. Native American Population by Region and Reservation

Region and Indian Reservation (Federal)	American Indian or Alaska Native
Alabama, Poarch Creek Reservation	98
Alaska, Ahtna Alaska Native Regional Corp.	707
Alaska, Aleut ANRC	2,150
Alaska, Annette Island Reserve	1,175
Alaska, Arctic Slope ANRC	5,050
Alaska, Bering Straits ANRC	6,915
Alaska, Bristol Bay ANRC	5,336
Alaska, Calista ANRC	19,617
Alaska, Chugach ANRC	1,696
Alaska, Cook Inlet ANRC	24,923
Alaska, Doyon ANRC	11,182
Alaska, Koniag ANRC	2,028
Alaska, NANA ANRC	5,944
Alaska, Sealaska ANRC	11,320
Arizona, Cocopah Reservation	519
Arizona, Ft. Apache Reservation	11,702
Arizona, Ft. McDowell Reservation	755
Arizona, Gila River Reservation	10,353
Arizona, Havasupai Reservation	453
Arizona, Hopi Reservation	6,442
Arizona, Hualapai Reservation	1,253
Arizona, Kaibab Reservation	131
Arizona, Maricopa (Ak Chin) Reservation	652
Arizona, New Mexico, Utah, Navajo Reservation	149,423
Arizona, New Mexico, Zuni Reservation	7,426
Arizona, Pascua Yqui Reservation	3,002
Arizona, Salt Ri. Reservation	3,366
Arizona, San Carlos Reservation	8,921
Arizona, Tohono O'odham Reservation	9,417
Arizona, Tonto Apache Reservation	115
Arizona, Yavapai-Apache Reservation	650
Arizona, Yavapai-Prescott Reservation	117
Arizona-California, Ft. Yuma Reservation	1,350
California, Alturas Rancheria	2
California, Aqua Pueblo Reservation	176
California, Arizona, Ft. Mojave Reservation	360
California, Barona Reservation	357
California, Benton Maiute Reservation	39
California, Big Lagoon Rancheria	19
California, Big Pine Reservation	287
California, Big Sandy Rancheria	77
California, Big Valley Rancheria	188
California, Bishop Reservation	950
California, Blue Lake Rancheria	33
California, Bridgeport Reservation	22
California, Cabazon Reservation	15
California, Cahuilla Reservation	106

Region and Indian Reservation (Federal)	American Indian or Alaska Native
California, Campo Reservation	245
California, Ceadarville Rancheria	22
California, Chemehuevi Reservation	149
California, Cold Springs Rancheria	177
California, Colusa Rancheria	59
California, Corttina Rancheria	18
California, Coyote Valley Reservation	84
California, Dry Creek Rancheria	36
California, Elk Valley Rancheria	40
California, Enterprise Rancheria	1
California, Ft. Bidwell Reservation	101
California, Ft. Independence Reservation	41
California, Greenville Rancheria	5
California, Grindstone Rancheria	141
California, Hoopa Valley Reservation	2,230
California, Hopland Rancheria	13
California, Jackson Rancheria	0
California, Jamul Indian Village	1
California, Karuk Reservation	46
California, La Jolla Reservation	294
California, La Posta Reservation	15
California, Laytonville Rancheria	160
California, Lone Pine Reservation	131
California, Lookout Rancheria	4
California, Los Coyotes Reservation	56
California, Manchester-Point Arena Ranch	151
California, Manzanita Reservation	56
California, Mesa Grande Reservation	60
California, Middletown Rancheria	51
California, Montgomery Rancherias	3
California, Mooretown Rancheria	116
California, Morongo Reservation	543
California, North Fork Rancheria	5
California, Pala Reservation	693
California, Pauma and Yuima Reservation	158
California, Pechanga Reservation	346
California, Picayune Rancheria	15
California, Pinoleville Rancheria	92
California, Quartz Valley Reservation	44
California, Redding Rancheria	29
California, Redwood Valley Rancheria Reservation	106
California, Resighini Rancheria	36
California, Rincon Rancheria	411
California, Roaring Creek Rancheria	9
California, Robinson Rancheria	118
California, Rohnerville Rancheria	62
California, Round Valley Reservation	56
California, Rumsey Rancheria	21
California, San Manuel Reservation	41

Region and Indian Reservation (Federal)	American Indian or Alaska Native
California, San Pasqual Reservation	341
California, Santa Rosa Rancheria	426
California, Santa Rosa Reservation	56
California, Santa Ynez Reservation	83
California, Santa Ysabel Reservation	225
California, Sherwood Valley Rancheria	131
California, Shingle Springs Rancheria	18
California, Smith Ri. Rancheria	41
California, Soboda Reservation	433
California, Stewarts Point Rancheria	55
California, Sulphur Bank Rancheria	53
California, Susanville Rancheria	220
California, Sycuan Reservation	21
California, Table Bluff Reservation	59
California, Table Mt. Rancheria	1
California, Torres-Martinez Reservation	195
California, Trinidad Rancheria	42
California, Tule Ri. Reservation	495
California, Tuolumne Rancheria	129
California, Upper Lake Rancheria	45
California, Viejas Reservation	146
California, Woodfords Comm	164
California, XL Ranch	11
California, Yurok Reservation	499
California, Arizona, Colorado River Reservation	2,292
Colorado, Southern Ute Reservation	10,805
Colorado, Utah, Ute Mt. Reservation	1,658
Florida, Big Cypress Reservation	110
Florida, Brighton Reservation	449
Florida, Hollywood Reservation	538
Florida, Immokalee Reservation	142
Idaho, Ft. Hall Reservation	3,648
Idaho, Kootenai Reservation	71
Idaho, Nez Perce Reservation	2,101
Iowa, Nebraska, Omaha Reservation	2,302
Iowa, Sac and Fox/Meskwaki Reservation	579
Kansas, Kickapoo (KS) Reservation	714
Kansas, Nebraska, Sac and Fox Reservation	49
Kansas, Prairie Ban Potawatomi Reservation	518
Louisiana, Chitimacha Reservation	285
Louisiana, Coushatta Reservation	20
Louisiana, Tunica-Biloxi Reservation	561
Michigan, Bay Mills Reservation	472
Michigan, Hannahville Comm	253
Michigan, Huron Potawatomi Reservation	9
Michigan, Isabella Reservation	1,397
Michigan, Lac Vieux Desert Reservation	113
Michigan, L'Anse Reservation	850
Michigan, Sault Ste. Marie Reservation	290

Region and Indian Reservation (Federal)	American Indian or Alaska Native
Minnesota, Bois Forte Reservation	464
Minnesota, Fond du Lac Reservation	1,353
Minnesota, Grand Portage Reservation	322
Minnesota, Leech Lake Reservation	4,561
Minnesota, Lower Sioux Reservation	294
Minnesota, Mille Lacs Reservation	1,034
Minnesota, Prairie Island Indian Community	166
Minnesota, Red Lake Reservation	5,071
Minnesota, Sandy Lake Reservation	66
Minnesota, Shakopee Mdeweak Sioux Comm	175
Minnesota, Upper Sioux Reservation	5,601
Minnesota, White Earth Reservation	3,374
Mississippi, Choctaw Reservation	4,087
Montana, Crow Reservation	5,165
Montana, Flathead Reservation	6,999
Montana, Ft. Belknap Reservation	2,790
Montana, Ft. Peck Reservation	6,391
Montana, Northern Cheyenne Reservation	4,029
Montana, Rocky Boy's Reservation	1,542
Kansas, Nebraska, Iowa Reservation	99
Nebraska, Santee Reservation	563
Nebraska, Winnebago Reservation	1,447
Nevada, Battle Mt. Reservation	112
Nevada, Campbell Ranch	207
Nevada, Carson Colony	241
Nevada, Dresslerville Colony	287
Nevada, Duckwater Reservation	116
Nevada, Elko Colony	627
Nevada, Ely Reservation	87
Nevada, Fallon Paiute-Shoshone Colony	105
Nevada, Fallon Paiute-Shoshone Reservation	534
Nevada, Idaho, Duck Valley Reservation	998
Nevada, Las Vegas Colony	100
Nevada, Lovelock Colony	86
Nevada, Moapa Ri. Reservation	165
Nevada, Oregon, Ft. McDermitt Reservation	301
Nevada, Oregon, Ft. McDermitt Reservation	301
Nevada, Pyramid Lake Reservation	1,221
Nevada, Reno-Sparks Colony	830
Nevada, South Fork Reservation	77
Nevada, Stewart Comm	150
Nevada, Summit Lake Re	11
Nevada, Utah, Goshute Reservation	97
Nevada, Walker Ri. Reservation	667
Nevada, Wells Colony	39
Nevada, Winnemucca Colony	44
Nevada, Yerington Colony	124
Nevada, Yomba Reservation	89
New Mexico, Acoma Pueblo	2,723

Region and Indian Reservation (Federal)	American Indian or Alaska Native
New Mexico, Cochiti Pueblo	695
New Mexico, Isleta Pueblo	2,675
New Mexico, Jemez Pueblo	1,941
New Mexico, Jicarilla Apache Reservation	2,475
New Mexico, Laguna Pueblo	3,669
New Mexico, Mescalero Reservation	2,888
New Mexico, Nambe Pueblo	455
New Mexico, Picuris Pueblo	166
New Mexico, Pojoaque Pueblo	264
New Mexico, San Felipe Pueblo	2,465
New Mexico,San Ildefonso Pueblo	528
New Mexico,San Juan Pueblo	1,328
New Mexico,Sandia Pueblo	500
New Mexico,Santa Ana Pueblo	473
New Mexico,Santa Clara Pueblo	1,329
New Mexico,Santo Domingo Pueblo	3,085
New Mexico,Taos Pueblo	1,331
New Mexico,Tesuque Pueblo	355
New Mexico, Zia Pueblo	645
North Carolina, Eastern Cherokee Reservation	6,665
North Dakota, Ft. Berthold Reservation	3,986
North Dakota, South Dakota, Standing Rock Reservation	5,964
North Dakota, Spirit Lake Reservation	3,317
North Dakota, Turtle Mt. Reservation	47
Oklahoma, Osage Reservation	6,410
Oregon, Burns Paiute Colony	148
Oregon, Celilo Village	39
Oregon, Coos, Lo. Umpqua, Siuslaw Reservation	10
Oregon, Coquille Reservation	128
Oregon, Cow Creek Reservation	5
Oregon, Grand Ronde Comm	30
Oregon, Klamath Reservation	4
Oregon, Siletz Reservation	182
Oregon, Umatilla Reservation	1,427
Oregon, Warm Springs Reservation	3,038
South Carolina, Catawba Reservation	362
South Dakota, Cheyenne River Reservation	6,249
South Dakota, Crow Creek Reservation	1,936
South Dakota, Flandreau Reservation	326
South Dakota, Lower Brule Reservation	1,237
South Dakota, North Dakota, Lake Traverse Reservation	3,453
South Dakota, Pine Ridge Reservation	12,985
South Dakota, Rosebud Reservation	7,747
South Dakota, Yankton Reservation	2,633
Texas, Alabama-Coushatta Reservation	480
Texas, Kickapoo (TX) Reservation	420
Texas, Ysleta Del Sur Pueblo	410

Region and Indian Reservation (Federal)	American Indian or Alaska Native
Utah, Paiute (UT) Reservation	250
Utah, Skull Valley Reservation	30
Utah, Uintah and Ouray Reservation	2,780
Washington, Chehalis Reservation	388
Washington, Colville Reservation	4,528
Washington, Hoh Reservation	81
Washington, Jamestown S'Klallam Reservation	0
Washington, Kalispel Reservation	180
Washington, Lower Elwha Reservation	208
Washington, Lummi Reservation	2,114
Washington, Makah Reservation	1,083
Washington, Muckleshoot Reservation	1,033
Washington, Nisqually Reservation	357
Washington, Port Gamble Reservation	505
Washington, Port Madison Reservation	497
Washington, Puyallup Reservation	1,324
Washington, Quainalt Reservation	1,051
Washington, Quileute Reservation	307
Washington, Sauk-Suiattle Reservation	35
Washington, Shoalwater Bay Reservation	44
Washington, Skokomish Reservation	510
Washington, Spokane Reservation	1,533
Washington, Stillaguamish Reservation	26
Washington, Swinomish Reservation	617
Washington, Tulalip Reservation	2,049
Washington, Upper Skagit Reservation	180
Washington, Yakama Reservation	7,289
Wisconsin, Bad River Reservation	1,096
Wisconsin, Forest Co. Potawatomi Comm	475
Wisconsin, Ho-Chunk Reservation	574
Wisconsin, Lac Courte Oreilles Reservation	2,147
Wisconsin, Lac du Flambeau Reservation	1,778
Wisconsin, Menominee Reservation	3,061
Wisconsin, Oneida (WI) Reservation	3,288
Wisconsin, Red Cliff Reservation	928
Wisconsin, Sokaogon Chippewa Comm	255
Wisconsin, St. Croix Reservation	443
Wisconsin, Stockbridge-Munsee Comm	796
Wyoming, Wind River Reservation	6,542

Source: 2000 U.S. Census.

3.7 AESTHETIC AND SCENIC RESOURCES

This section describes the aesthetic and scenic resources that may be affected by carbon sequestration projects.

In this document, the term "aesthetics" is defined as the study of beauty and of judgments concerning beauty. The term "scenic" pertains to natural or natural-appearing landscapes and conditions that afford pleasant views of landscape attributes or positive cultural attributes. Principal aesthetic and scenic resources include National Parks, forests, nature areas, and other resources designated for preservation and management by the Federal government. Additional aesthetic and scenic resources include parks, forests, nature areas, and other resources designated for preservation and management by states and local jurisdictions. Visibility is an important park resource and one of the major reasons people visit national parks. "Visibility is made up of two main components: (1) how far you can see a distant object, and (2) how clearly you can see a distant object." The largest threat to visibility is haze. Haze is caused by particulate matter (PM), which is "made up of tiny particles of soot, dust, and other materials from diesel engines, power plants, wood stoves, and dirt roads." The PM scatters and absorbs light that affects the clarity of objects and renders distant views unclear (NPS, 2005)

3.7.1 National Context

The National Park System (NPS) encompasses approximately 84.5 million acres, of which more than 4.2 million acres remain in private ownership. Table 3-13 summarizes the NPS aesthetic and scenic resources for the entire country (NPS, 2003). In this table and throughout this section, the following definitions apply:

- "International Historic Sites" include all international areas containing a single historical feature upon which the site is based.
- "National Battlefield Parks, National Battlefield Sites, National Battlefields, and National Military Parks" include areas containing historical military lands.
- "National Historic Sites" include all national areas containing a single historical feature upon which the site is based.
- "National Historical Parks" include historic parks that extend beyond single properties or buildings.
- "National Lakeshores" are all located on the Great Lakes and closely parallel the seashores in character and use.
- "National Memorials" include areas that are commemorative of a historic person or event.
- "National Monuments" include landmarks, structures, and other objects of historic or scientific interest situated on government lands.
- "National Parks" include large natural places that prohibit hunting, mining, and consumptive activities and which have a wide variety of attributes that may or may not include significant historic assets.
- "National Preserves" include areas of natural or scientific significance within the boundaries of other park systems.
- "National Recreation Areas" include water and lands that combine scarce open spaces with the preservation of significant historic resources and natural areas in order to provide recreation for large numbers of people.

- “Natural Reserves” include areas having characteristics of National Parks but which permit public hunting, trapping, oil/gas exploration and extraction.
- “National Rivers” include national rivers (wild rivers and scenic rivers are categorized separately).
- “National Scenic Trail” includes over 3,600 miles of linear parklands authorized under the National Trails System Act of 1968.
- “National Seashores” include ten national seashores along the Atlantic, Gulf, and Pacific coasts.
- “National Wild and Scenic Rivers” include rivers designated under the Wild and Scenic Rivers Act of 1968.
- “Parks (other)” includes other national land areas that bear unique titles.
- “Parkways” includes roadways and parkland paralleling a roadway intended for scenic motoring (NPS, 2002).

Additionally, there are numerous state parks, wildlife refuge areas, wildlife management areas, wilderness areas, trails, rivers, lakes and shores, scenic byways, archeological sites, recreation areas, and historic sites that further contribute to the scenic and aesthetic resources of the regions.

Table 3-13. National Park Service Aesthetic and Scenic Resources (2003) in the U.S.

Aesthetic and Scenic Resources	Entire United States (acres)
International Historic Sites	45
National Battlefield Parks	10,472
National Battlefield Sites	1
National Battlefields	13,405
National Historic Sites	37,657
National Historical Parks	167,102
National Lakeshores	228,867
National Memorials	9,100
National Military Parks	40,759
National Monuments	2,335,063
National Parks	51,888,804
National Preserves	24,153,467
National Recreation Areas	3,692,557
National Reserves	33,431
National Rivers	426,353
National Scenic Trails	236,573
National Seashores	595,046
National Wild & Scenic Rivers	314,130
Parks (Other)	39,622
Parkways	175,786
Total	84,238,386

Source: NPS, 2003.

3.7.2 State Resources

A summary of National aesthetic and scenic resources by state is provided in Table 3-14. Additional National Park and other scenic resources that cross state boundaries are listed in Table 3-15. Extent of State forests and parks by state is provided in Table 3-16.

Table 3-14. National Park Service Aesthetic and Scenic Resources (2005)

State	Acreage	Annual Visitors
Alabama	16,131	747,617
Alaska	54,625,602	2,359,084
Arizona	2,010,561	10,799,429
Arkansas	104,928	2,546,209
California	4,831,706	33,400,604
Colorado	516,553	5,352,839
Connecticut	74	11,129
Delaware	0	0
Florida	2,571,213	7,794,294
Georgia	55,785	5,652,269
Hawaii	364,999	5,415,722
Idaho	735,753	446,507
Illinois	13	419,552
Indiana	15,293	2,402,913
Iowa	2,713	240,760
Kansas	11,792	121,419
Kentucky	53,175	3,361,946
Louisiana	21,128	498,446
Maine	47,435	2,051,484
Maryland	17,365	3,242,054
Massachusetts	46,376	9,088,046
Michigan	718,186	1,716,599
Minnesota	272,967	628,087
Mississippi	1,902	5,743,683
Missouri	83,376	4,815,314
Montana	1,016,967	3,877,478
Nebraska	29,345	226,810
Nevada	77,180	5,847,070
New Hampshire	148	26,943
New Jersey	45,043	5,487,875
New Mexico	391,029	1,650,441
New York	24,345	16,035,410
North Carolina	60,116	19,392,624
North Dakota	72,205	541,217
Ohio	34,154	2,798,434
Oklahoma	10,175	1,310,523
Oregon	199,071	901,254
Pennsylvania	16,403	9,119,510
Rhode Island	5	50,668
South Carolina	32,583	1,406,724
South Dakota	273,618	3,733,160

Tennessee	11,416	7,678,481
Texas	1,236,404	5,372,427
Utah	855,390	8,046,646
Vermont	643	28,660
Virginia	253,492	22,930,227
Washington	1,964,392	7,091,427
West Virginia	88,006	1,641,563
Wisconsin	69,372	436,093
Wyoming	344,150	5,453,845

Source: Street, 2006.

Table 3-15. Additional National Park Service Aesthetic and Scenic Resources (2005)

States	Sites
Alaska to Washington	13,192 acres of the Klondike Gold Rush National Historical Park
Arizona and Utah	1,254,429 acres of Glen Canyon National Recreation Area
Arkansas and Oklahoma	75 acres of Fort Smith National Historical Site
California and Nevada	3,372,402 acres of the Death Valley National Park
Colorado and Utah	210,278 acres of Dinosaur National Monument
Colorado and Utah	785 acres of Hovenweep National Monument
Georgia and Tennessee	9,036 acres of the Chickamauga & Chattanooga National Military Park
Idaho, Montana, and Wyoming	2,219,791 acres of Yellowstone National Park
Kentucky and Tennessee	125,310 acres of Big South Fork National River and Recreation Area
Kentucky, Tennessee and Virginia	20,512 acres of Cumberland Gap National Historic Park
Maine to Georgia	226,498 acres of Appalachian National Scenic Trail
Maryland and Virginia	39,727 acres of the Assateague Island National Seashore
Maryland and Virginia	7,239 acres of the George Washington Memorial Parkway
Maryland, Virginia, and Washington, D.C.	6,693 acres of National Capitol Parks
Maryland, Virginia and West Virginia	3,646 acres of Harper's Ferry National Historical Park
Maryland, West Virginia and Washington, D.C.	19,586 acres of the C&O Canal National Historical Park
Minnesota and Wisconsin	92,748 acres of the Saint Croix National Seashore
Mississippi to Florida	137,990 acres of the Gulf Islands National Site
Mississippi to Tennessee	10,995 acres of Natchez Trace National Scenic Trail
Missouri and Illinois	91 acres of the Jefferson National Memorial which extends from Missouri to Illinois.
Montana and North Dakota	444 acres of the Fort Union Trading Post National Historical Site;
Montana and Wyoming	120,296 acres of Bighorn Canyon National Recreation Area
Nevada to Arizona	1,495,664 acres of the Lake Mead National Recreation Area
New Jersey and New York	26,607 acres of Gateway National Recreation Area
New Jersey and Pennsylvania	66,739 acres of Delaware Water Gap National Recreation Area
New Jersey and Pennsylvania	1,973 acres of Delaware National Scenic River
New York and New Jersey	61 acres of Statue of Liberty National Monument
New York and Pennsylvania	75,000 Upper Delaware Scenic and Recreational River
North Carolina and Virginia	93,735 acres of the Blue Ridge Parkway
South Dakota and Nebraska	34,159 acres of the Missouri River National Recreational River
Tennessee and Mississippi	51,824 acres of the Natchez Trace Parkway
Tennessee and North Carolina	522,199 acres of the Great Smoky Mountains National Park

Table 3-16. State Forests and Parks

State	State Forests		State Parks	
	Number	Acreage	Number	Acreage
Alabama	21	48,000	22	45,614
Alaska	NA	NA	>100	3,500,000
Arizona	NA	NA	28	NA
Arkansas	NA	NA	51	NA
California	NA	NA	278	1,500,000
Colorado	1	71,000	44	160,000
Connecticut	94	170,000	94	32,960
Delaware	3	>15,000	14	>20,000
Florida	31	>890,000	159	>723,000
Georgia	6	63,294	64	65,066
Hawaii	19	>109,000	52	25,000
Idaho	NA	881,000	30	>43,000
Illinois	NA	NA	NA	NA
Indiana	NA	NA	23	56,409
Iowa	10	43,917	84	53,000
Kansas	NA	NA	24	NA
Kentucky	5	35,809	52	NA
Louisiana	1	8,000	35	NA
Maine	1	21,000	>30	NA
Maryland	7	136,907	40	90,293
Massachusetts	NA	NA	NA	NA
Michigan	NA	NA	96	265,000
Minnesota	58	<4,000,000	72	NA
Mississippi	NA	NA	24	NA
Missouri	NA	NA	NA	NA
Montana	7	214,000	110	18,273
Nebraska	NA	NA	87	NA
Nevada	NA	NA	24	NA
New Hampshire	NA	NA	72	NA
New Jersey	11	NA	42	NA
New Mexico	NA	NA	31	NA
New York	2	2,750,000	176	NA
North Carolina	NA	NA	29	NA
North Dakota	NA	NA	17	NA
Ohio	20	>183,000	74	>204,000
Oklahoma	NA	NA	50	NA
Oregon	NA	780,000	231	95,462
Pennsylvania	NA	>2,000,000	116	NA
Rhode Island	NA	NA	14	NA
South Carolina	4	NA	47	>80,000

State	State Forests		State Parks	
	Number	Acreage	Number	Acreage
South Dakota	NA	NA	12	NA
Tennessee	15	162,371	54	NA
Texas	5	7,314	115	>600,000
Utah	NA	NA	NA	NA
Vermont	NA	300,000	52	NA
Virginia	16	750,000	34	NA
Washington	NA	2,100,000	120	NA
West Virginia	9	79,502	37	74,508
Wisconsin	NA	NA	NA	NA
Wyoming	NA	NA	NA	NA

NA = data not available
Source: Infoplease, 2006.

3.7.2.1 Unique Geographic Features and Scenic Resources

A brief list of unique geographic features and scenic resources by state is provided in Table 3-17.

Table 3-17. Unique Geographic Features and Scenic Resources

State	Unique Geographic Features and Scenic Resources
Alaska	Denali National Park, Mendenhall Glacier, and the Katmai National Park that includes the "Valley of Ten Thousand Smokes," an area of active volcanoes;
Arizona	The Grand Canyon National Park is one of the most studied geologic landscapes in the world. The park encompasses 1,218,375 acres, lies on the Colorado Plateau in northwestern Arizona, contains several major ecosystems, and "offers an excellent record of three of the four eras of geological time, a rich and diverse fossil record, a vast array of geologic features and rock types, and numerous caves containing extensive and significant geological, paleontological, archeological and biological resources" (NPS, 2005c)
California	Yosemite National Park (California), "embraces a spectacular tract of mountain-and-valley scenery in the Sierra Nevada, which was set aside as a national park in 1890. The park harbors a grand collection of waterfalls, meadows, and forests that include groves of giant sequoias, the world's largest living things" (NPS, 2005d). Also Sequoia and Kings Canyon National Parks and Pacific Coast Highway.
Colorado	Breathtaking scenery and world-class skiing make Colorado a prime tourist destination; however, Revised Statute 2477 threatens scenic quality of these areas by allowing "the right of way for the construction of highways over public lands, not reserved for public uses" (State of Colorado, 2005). Colorado includes more than 1,000 Rocky Mountain peaks over 10,000 ft high and 54 towering peaks above 14,000 ft. Pike's Peak is the most famous of these mountains.
Florida	Florida's Everglades National Park, the Nation's only subtropical preserve, which is formed by a freshwater river 6 inches deep and 50 miles wide
Gulf Coast States	Gulf Coast Resort areas
Hawaii	In the northwest interior of Kaua'i is Waimea Canyon, also known as the Grand Canyon of the Pacific, and the high altitude Alaka'i Swamp. In the center of Kaua'i is the top of the inactive Wai'ale'ale volcano. The summit gets an average of 1.5 inches of rain everyday, making it the wettest palce on earth.(Wikipedia, 2006).
Idaho	Idaho has numerous lakes, glaciers, and mountains, such as Craters of the Moon National Monument. Idaho's many streams and lakes provide fishing, camping, and boating sites. The nation's largest elk herds draw hunters from all over the world, and the famed Sun Valley resort attracts thousands of visitors to its swimming, golfing, and skiing facilities" (Infoplease, 2004).
Indiana	Wyandotte Cave located in Indiana, which is one of the largest in the U.S.
Kentucky	Mammoth Cave National Park featuring an extensive cave system.

State	Unique Geographic Features and Scenic Resources
Maryland	Maryland's Chesapeake Bay is one of the largest and most productive estuaries in the U.S. Over 200 miles long and fed by thousands of rivers and streams, the bay's watershed covers nearly 64,000 square miles.
Michigan	Michigan alone borders on four of the five Great Lakes and includes 3,288 miles of Great Lake shoreline.
Minnesota	Minnesota's key scenic resource is its more than 10,000 lakes and Great Lake shoreline.
Montana	Glacier National Park, on the Continental Divide, has 60 glaciers, 200 lakes, and many streams with good trout fishing" (Pearson Education, 2004).
Nevada/ Arizona	Hoover Dam (Nevada and Arizona), one of the largest dams in the world and a principal source of irrigation, flood control, and electrical power in the Southwest.
New Mexico	*C*arlsbad Caverns National Park.
New York	Niagara Falls is a set of massive waterfalls located on the Niagara River on the border between the U.S. and Canada (Wikipedia, 2006a).
North Carolina	The Great Smoky Mountains, the Blue Ridge National Parkway, and the Cape Hatteras and Cape Lookout National Seashores in North Carolina;
North Carolina/ Tennessee	Encompassing 800 square miles, the Great Smoky Mountains National Park in North Carolina and Tennessee is one of the largest protected areas in the Eastern U.S. With more than 9 million visitors annually, this park is threatened by acid deposition, O3 pollution, and mercury pollution.
Oregon	Crater Lake in south central Oregon, which includes a deep blue lake created by the eruption and collapse of Mt. Mazama almost 7,000 years ago
Pennsylvania	The "Grand Canyon of Pennsylvania" located in Tioga County and covering 300,000 acres.
South Dakota	Badlands National Park and Mount Rushmore (South Dakota)
Utah	Utah is a popular vacationland with 11,000 miles of fishing streams and 147,000 acres of lakes and reservoirs (Infoplease, 2004).
Virginia	Shenandoah National Park draws up to 2 million visitors per year. Air quality is an important aspect of maintaining the scenic quality of the area. Because the park is located downwind of a number of major industrial and urban areas, air pollution, particularly during the summer months, has significantly degraded the distance, color, contrast, and landscape details of park views from Skyline Drive. In addition, "foliar injury caused by ground-level ozone has impaired the aesthetics of many of the park's 40 known ozone-sensitive plant species." (NPS, 2005b)
Washington	Mount St. Helens (Washington), a peak in the Cascade Range, which experienced a major eruption in May 1980.
West Virginia	Blackwater Canyon located below Blackwater Falls State Park and surrounded by the Monongahela National Forest in West Virginia.
Wyoming	Yellowstone National Park, Grand Teton Range, and Devil's Tower.

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3.8 LAND USE

This section describes land uses that may be affected by carbon sequestration projects.

3.8.1 National Context

The U.S. has a total land area of approximately 2,263 million acres. Table 3-18 summarizes the major land uses for the entire country (Vesterby and Krupa, 2001). In this table and throughout the land use section, the following definitions apply:

- "Cropland" includes all land in crop production, plus idle cropland and croplands used only for pasture.
- "Grassland" includes permanent grassland, plus non-forested pasture and range.
- "Forest" includes lands classified as such by the U.S. Forest Service, excluding approximately 105 million acres in parks and other special uses.
- "Special use" land includes these 105 million acres, plus other lands used for national and state parks, wilderness and wildlife areas, Federal installations (mainly DOD and DOE), rural highways and roads, railroads, rural airports, and farmsteads.
- "Urban" land includes urbanized areas and jurisdictions with populations of 2,500 or more.
- "Other" land includes marshes, open swamps, desert, tundra, bare rock areas, and other uses not categorized.

Table 3-18. Major Land Uses (1997) in the United States (million acres)

Land Use	Entire United States (million acres)	Portion of Total
Cropland	455	20%
Grassland	580	26%
Forest	641	28%
Special Use	286	13%
Urban	66	3%
Other	235	10%
Total	2,263	

Source: Vesterby and Krupa, 2001.

Nearly half of the land area (46 percent) is cropland or grassland; forests account for an additional 28 percent of the total land area. Also, the special use category includes approximately 247 million acres of land used for national and state parks, wilderness and wildlife areas, and Federal installations, which represent an additional 11 percent of the total land. Furthermore, the other use category includes vegetated marshes and swamps. Therefore, at least 1,923 million acres (approximately 85 percent) of land supports substantial vegetation. This acreage provides a significant natural sink for terrestrial carbon sequestration with abundant opportunities for enhancement.

With respect to the distributions of major land uses throughout the 50 states, general patterns are indicated in Figure 3-27. Forested lands are significant in the southeastern, upper mid-western, and northwestern states, as well as in Alaska. Grasslands predominate in the plains and mountain states. Croplands are significant in mid-western, plains, and southeastern states. The west coast states, except Alaska, have significant acreage in all three categories.

Since 1959, the most significant trend in major land use on a nationwide basis has been the increase in special-use areas (132 percent), generally as a result of wilderness and wildlife area designations. Also, grassland has decreased by 8 percent since 1959, and cropland has declined by about 3 percent since 1978. More recently, in the years between 1992 and 1997, grassland decreased by 2 percent, while cropland and forests decreased by 1 percent each. During the same 5-year interval, special use lands increased by 2 percent and urban lands increased by nearly 11 percent. It can reasonably be assumed that these recent trends have continued to the present.

Urban lands nationwide comprised 66 million acres in 1997, representing approximately 3 percent of the total land area. Since 1960, urban land acreage nationwide increased by approximately 157 percent. The highest concentrations of urban lands are situated in the northeastern, upper mid-western, southeastern, and west coast states. Urban centers having the highest population density are illustrated in Figure 3-28.

The abundance of unmineable coal seams, deep-saline water-bearing formations, and depleted oil reserves in regions throughout the 48 conterminous states is important for geologic sequestration. These resources are described in more detail in Section 3.3, Geologic Resources.

The U.S. has approximately 12,383 statute miles of seacoast based on the general outline of seacoast measured in 30 minutes of latitude on charts as near a scale of 1:1,200,000 as possible (Pearson Education, 2004). The proximity to the ocean is of significance for potential future ocean sequestration projects.

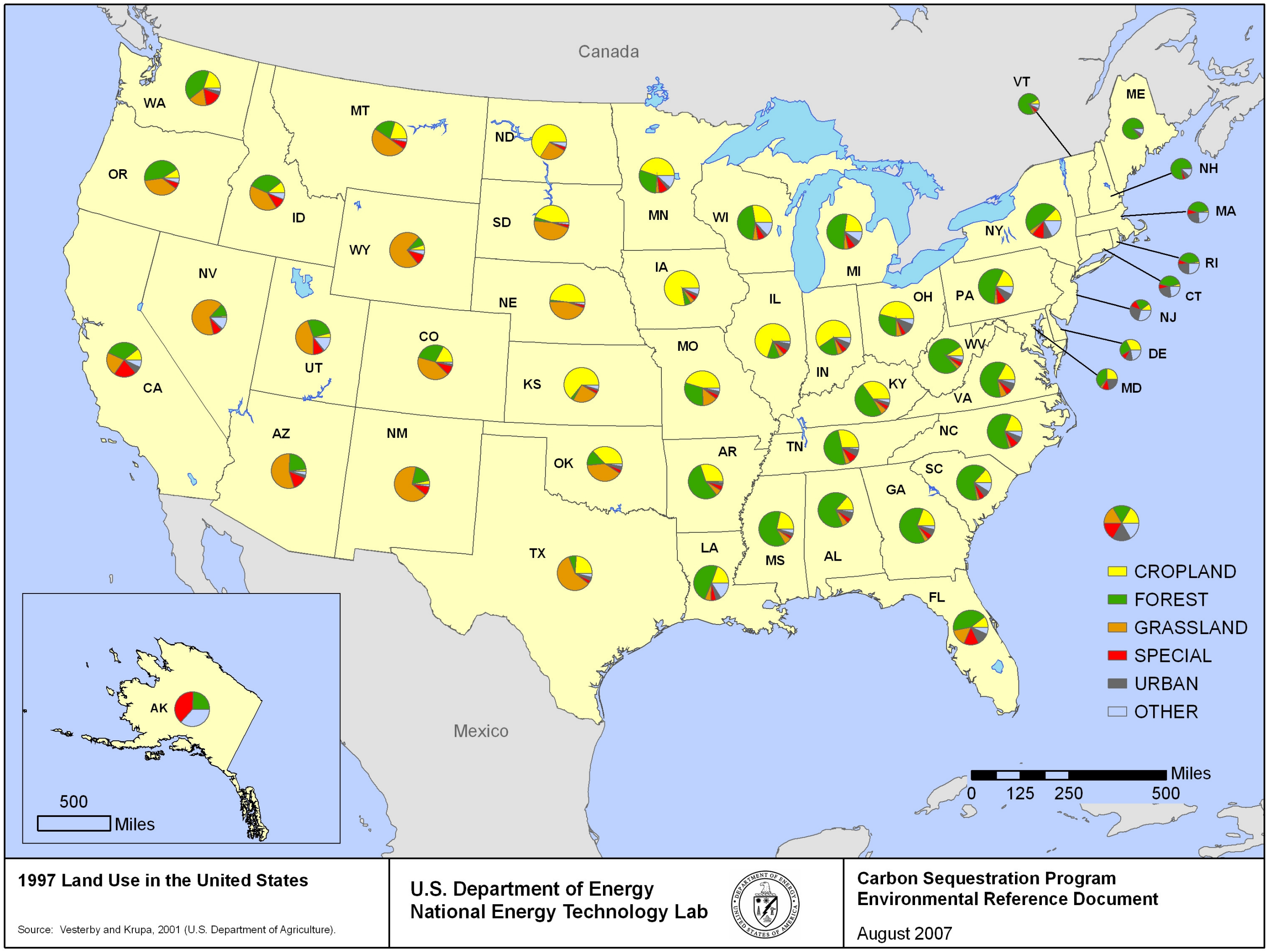

Figure 3-27. Land Use

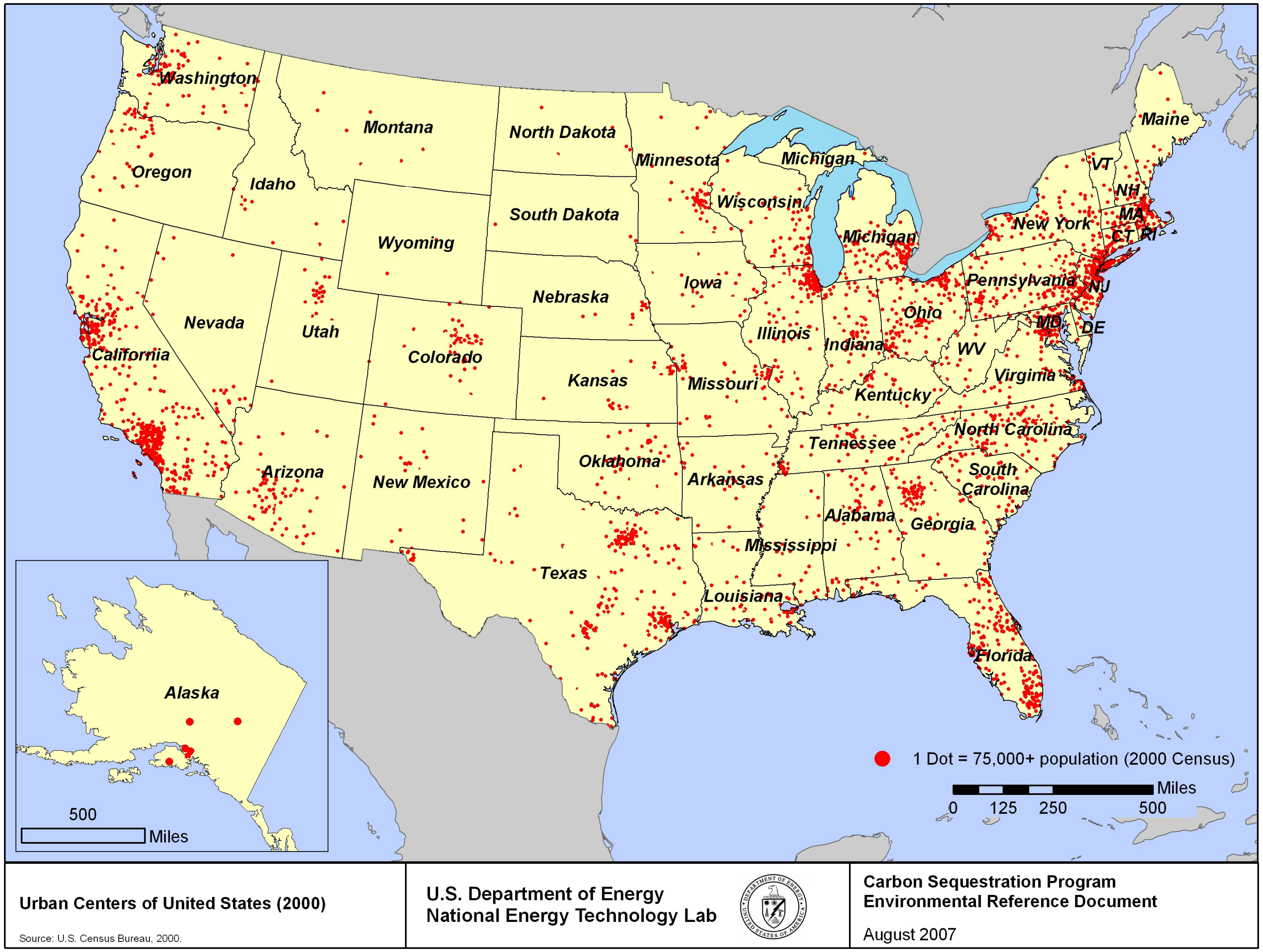

Figure 3-28. Population

3.8.2 State Land Uses

Land uses by state are shown in Table 3-19.

Table 3-19. Major Land Uses (1997) by State

State	Cropland	Grassland	Forest	Special Use	Urban	Other	Total
	in 1,000 Acres						
Alabama	4,471	1,860	21,911	1,423	2,000	815	32,480
Alaska	68	1,226	87,936	143,013	567	132,229	365,039
Arizona	1,254	40,509	16,306	10,092	1,746	2,825	72,732
Arkansas	10,082	2,006	18,392	1,450	931	467	33,328
California	10,628	22,343	32,579	20,996	5,922	7,355	99,823
Colorado	11,415	27,867	18,781	5,699	1,070	1,553	66,385
Connecticut	166	30	1,682	299	910	923	4,011
Delaware	451	8	376	102	154	313	1,405
District of Columbia	0	0	0	0	39	39	78
Florida	3,650	5,455	14,605	4,676	3,902	2,270	34,558
Georgia	7,329	1,336	23,004	1,854	2,132	1,412	37,068
Hawaii	293	961	1,189	769	678	898	4,789
Idaho	5,766	21,165	17,123	5,266	233	3,408	52,961
Illinois	24,925	1,559	4,058	1,901	2,215	922	35,580
Indiana	13,689	1,158	4,342	1,102	1,325	1,341	22,957
Iowa	27,911	1,477	1,944	1,550	801	2,077	35,760
Kansas	33,708	12,560	1,492	1,620	693	2,294	52,367
Kentucky	8,860	1,491	12,348	996	793	940	25,429
Louisiana	5,485	1,582	13,691	1,395	1,282	4,447	27,882
Maine	466	37	16,952	520	581	1,778	20,334
Maryland	1,555	208	2,424	731	1,208	130	6,256
Massachusetts	211	35	2,675	553	1,515	1,542	6,531
Michigan	8,304	1,606	18,667	2,468	1,896	3,417	36,358
Minnesota	22,839	1,544	14,820	4,398	1,419	5,934	50,954
Mississippi	6,464	1,946	18,589	848	852	1,327	30,025
Missouri	20,013	6,010	13,411	1,740	1,390	1,531	44,095
Montana	18,573	46,039	19,165	6,414	196	2,769	93,156
Nebraska	23,555	21,828	797	1,423	294	1,305	49,202
Nevada	867	46,278	8,199	5,726	801	8,403	70,274
New Hampshire	112	40	4,551	317	376	720	6,116
New Jersey	634	29	1,507	728	1,712	1,850	6,460
New Mexico	2,427	52,188	14,084	6,360	636	1,979	77,674
New York	4,112	1,314	15,405	3,810	2,431	5,581	32,654
North Carolina	5,890	814	18,638	2,264	1,760	1,814	31,180
North Dakota	28,818	11,329	441	1,489	129	1,950	44,156
Ohio	12,026	1,376	7,567	1,153	2,559	1,528	26,209
Oklahoma	16,336	17,314	6,233	1,477	1,473	1,120	43,953

State	Cropland	Grassland	Forest	Special Use	Urban	Other	Total
	in 1,000 Acres						
Oregon	5,338	22,395	26,664	3,593	610	2,840	61,440
Pennsylvania	5,181	910	15,852	2,379	2,146	2,218	28,685
Rhode Island	30	3	356	61	214	220	883
South Carolina	2,532	465	12,418	1,032	1,102	1,722	19,271
South Dakota	21,765	22,594	1,588	1,575	150	901	48,573
Tennessee	7,491	1,123	13,265	2,203	1,695	603	26,380
Texas	40,040	98,059	11,767	5,363	5,697	6,699	167,625
Utah	2,045	23,737	13,832	5,058	549	7,367	52,588
Vermont	484	212	4,462	337	120	425	6,040
Virginia	4,340	1,533	15,345	1,468	1,654	1,003	25,343
Washington	8,400	7,406	17,418	6,639	1,371	1,378	42,612
West Virginia	1,411	481	11,899	699	288	637	15,415
Wisconsin	9,561	1,844	15,701	2,182	1,113	4,359	34,760
Wyoming	3,080	44,873	5,085	6,332	206	2,571	62,147

Source: Vesterby and Krupa, 2001.
(See land use definitions in Section 3.8.1)

3.9 MATERIALS AND WASTE MANAGEMENT

A range of chemical materials would be expected to be used in carbon sequestration projects. The sequestration technologies would also produce certain solid and hazardous wastes. This section describes the types of materials and wastes that are anticipated to be part of the projects.

3.9.1 Materials

The major types of chemical materials that would be used in processes that would be part of the potential geologic sequestration project include: fuels, tracers, and process chemicals as illustrated in Table 3-20. The table also lists the model projects and the various types of materials that may be used.

Fuels that are most likely to be used for project processes are electricity, diesel fuel, natural gas, and propane. The selection of the specific fuel type depends upon the location of the project and availability of fuels (some facilities may not be close enough to existing power lines to use that service) and the purpose of the fuel (operate electrical equipment or heat a process stream).

Process chemicals can include chemicals used for chiller operation, catalysts or reagents to facilitate the separation of gases in a process stream, and compounds to assist in process stream phase change. Amine and soda ash are process chemicals that would be expected to be used in post combustion capture projects. Anhydrous ammonia is a process chemical commonly used to operate a commercial size chiller for compression of gases. Amine is a process chemical that would be used for some projects. Amine (Diethanolamine or DEA) is corrosive and toxic. As such, care would be taken to handle and store the materials properly to avoid spills, leaks or misuse. The Material Safety Data Sheet (MSDS) for DEA (Mallinkrodt Baker, 2005) lists the chemical as having a moderate health rating (2), Slight flammability rating, Moderate Reactivity Rating and as Severe rating for contact.

Table 3-20. Project Materials for Selected Carbon Sequestration Projects.

Model Project	Material Type	Purpose	Example Material
Post Combustion Capture	Fuel	Electric operated equipment	Line power from collocated power plant
	Fuel	Standby generator	Diesel fuel
	Solvent	Process chemical used in the capture of CO_2	Amine
	Caustic	Process chemical used in the capture of CO_2	Soda Ash
CO_2 Compression and Transportation	Fuel	Electric operated equipment	Line power or diesel generator
	Fuel	Standby generator	Diesel fuel
	Chiller Process Chemicals	Compressor operation	Anhydrous ammonia
Coal Seam Sequestration	Fuel	Heater operation	Natural Gas or diesel fuel
	Fuel	Electric operated equipment	Line power or diesel generator
	Fuel	Standby generator	Diesel fuel
	Tracer	Used to determine the fate and transport of the injected CO_2 stream	See Table 3-21
Saline Formation Injection	Fuel	Electric operated equipment	Line power or diesel generator
	Standby generator	Electric operated equipment	Diesel fuel
	Tracer	Used to determine the fate and transport of the injected CO_2 stream	See Table 3-21
Enhanced Oil Recovery	Fuel	Electric operated equipment	Line power or diesel generator

Model Project	Material Type	Purpose	Example Material
	Fuel	Standby generator	Diesel fuel
	Tracer	Used to determine the fate and transport of the injected CO_2 stream	See Table 3-21
Terrestrial Sequestration - Reforestation	Fuel	Machinery such as tractors, disks, and rangeland seeders.	Diesel fuel
	Herbicide	Control of weeds or other invasive plant species that could preclude the success of reforestation	To be determined
	Pesticide	Control of insect populations that could threaten the success of reforestation.	To be determined
Co-Sequestration	Fuel	Electric operated equipment	Line power or diesel generator
		Standby generator	Diesel fuel
	Solvent	Process chemical used in the capture of CO_2	Amine

Tracers are used in field validation projects to help the researchers learn about the behavior of the CO_2 stream that is injected into a formation. The chemicals are selected because:

- they can be easily measured at monitoring wells
- they are not commonly found in nature
- they do not rapidly degrade or interact with compounds in the formation or the injectate
- they display low toxicity to biota.

Examples of tracers that have been proposed for use in carbon sequestration field tests are listed in Table 3-21 from the Draft Environmental Assessment for Pilot Experiment for Geological Sequestration of CO_2 in Saline Aquifer Brine Formations (DOE, 2003). This experiment was begun in the fall of 2004 in Frio County, Texas.

A variety of construction materials would be used in the construction activities including: concrete, structural steel, plastics, composites, sheetrock, paint, floor coverings, and other items. These are common items used in new industrial construction that would not require special production capability for these materials to be obtained. Leftover materials will be properly disposed or reused as appropriate.

3.9.2 Waste Management

Several types of waste are typically associated with carbon sequestration projects as listed in Table 3-22. These wastes would not exist prior to implementation of the projects. However, if a carbon sequestration project is collocated with another type of energy project (i.e., coal-fired power plant or oil and gas field), a range of wastes would already be generated and managed for the other energy projects. Where existing projects are already in place, a system of waste management could potentially be utilized by the carbon sequestration project.

The quantities of wastes and properties of those wastes would be determined during the project development phase. NEPA studies for future projects should evaluate the extent of existing waste management facilities including permitted landfill operations. They should also address the extent and capabilities of local waste management services to accommodate wastes that would be newly generated by the proposed project.

Table 3-21. Tracers Proposed for Use in Saline CO_2 Injection Pilot Experiment

Tracer	Concentration (Injectate)	Concentration Produced Fluids	Maximum Total Weight	Comments
FLUTEC-TG PMCH (perfluoromethylcyclohexane)	30 µg/mL (30 ppm)	1 ng/mL (1 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG PTMCH (perfluoro-1,3,5-trimethyleyeclohexane)	30 µg/mL (30 ppm)	1 ng/mL (1 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG o-PDMCH (perfluoro-1,2-dimethyleclohexane)	30 µg/mL (30 ppm)	1 ng/mL (1 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG m-PDMCH (perfluoro-1,3-dimethylcyclohexane)	7 µg/mL (7 ppm)	0.2 ng/mL (0.2 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG p-PDMCH (perfluoro-1,4-dimethylcyclohexane)	7 µg/mL (7 ppm)	0.2 ng/mL (0.2 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG PMCH (perfluorodimethylcyclopentane)	30 µg/mL (30 ppm)	1 ng/mL (1 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG PDMCB (perfluorodimethylcyclobutane)	7 µg/mL (7 ppm)	0.2 ng/mL (0.2 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
FLUTEC-TG PECH (perfluorodimethylcyclohexane)	7 µg/mL (7 ppm)	0.2 ng/mL (0.2 ppb)	Perfluoro-carbons: 60 kg total	No known human- or eco-toxicity
^{20}Ne (Neon 20)	30.3 ppm	Variable	0.63 kg	No known human- or eco-toxicity
^{36}Ar (Argon 36)	164 ppm	Variable	3.42 kg	No known human- or eco-toxicity
^{84}Kr (Krypton 84)	7.64 ppm	Variable	0.16 kg	No known human- or eco-toxicity
^{132}Xe (Xenon 132)	0.4 ppm	Variable	0.01 kg	No known human- or eco-toxicity
Eosin	1 ppm	5 ppb	10 kg	No known human- or eco-toxicity

Source: DOE, 2003.

Table 3-22. Waste Types

Model Project	Waste Type	Typical Disposal
Post Combustion Capture	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
CO_2 Compression and Transportation	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
Coal Seam Sequestration	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
	Drill cuttings	Onsite or local landfill
	Circulation mud pit	Onsite or local landfill
	Produced water	Depends on local conditions

Model Project	Waste Type	Typical Disposal
Saline Formation Injection	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
	Drill cuttings	Onsite or local landfill
	Circulation mud pit	Onsite or local landfill
	Produced water	Depends on local conditions
Enhanced Oil Recovery	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
	Drill cuttings	Onsite or local landfill
	Circulation mud pit	Onsite or local landfill
	Produced water	Depends on local conditions
Terrestrial Sequestration - Reforestation	Wastewater	Onsite treatment or discharge to a permitted treatment works
	Municipal waste	Local permitted municipal landfill
	Unused herbicides and pesticides	Permitted treatment, storage and disposal facility
	Green waste from land clearing	Compost facility

3.10 HUMAN HEALTH EFFECTS AND SAFETY

This section describes the context for consideration of human health effects and safety that would be created by future carbon sequestration projects. Two aspects of worker health and safety impacts are discussed: worker injuries and worker fatalities that are associated with the construction or operation of carbon sequestration projects.

Public health and safety related to carbon sequestration projects can be measured on the basis of many factors. For this document the existing environment is assumed to consist of an existing industrial facility in almost every case, except for terrestrial sequestration. Many industrial facilities use hazardous or toxic materials in the processes. Under normal conditions these materials can be used safely assuming proper safety precautions are followed. Using highly toxic materials poses additional risk of accidental releases of toxic air emissions that pose a risk to the public in the surrounding area. The EPA issued rules to implement provisions of the Clean Air Act Amendments of 1990 that requires the owner of a facility that uses extremely toxic materials to prepare a Risk Management Plan (RMP). If an existing facility does not require an RMP it is assumed to pose a smaller risk of accidental release of toxic materials to the air than a facility that does require an RMP. The following sections explain the concept in more detail.

3.10.1 National Context

In general, most of the Carbon Sequestration projects analyzed in this document are not stand-alone projects. For example, a Post-Combustion Capture Project would be collocated with an existing coal-fired power plant. Therefore, health and safety aspects of sequestration components or technologies may be similar to their partner site or industry. A listing of a representative "existing facilities" is presented to use as a backdrop for comparison of environmental impacts that will be discussed in Chapter 4. Table 3-23 lists potential carbon sequestration projects and representative existing facilities.

Table 3-23. Carbon Sequestration Projects and Anticipated Co-Located Facilities

Project	Primary Existing Facility	Industry Category	Industry Code (NAICS Code (1))	Incidence rates(2) of nonfatal occupational injuries and illnesses	Occupational fatalities in 2003	Risk Management Plan Required for use of Extremely Hazardous Materials (Compounds that trigger preparation of an RMP)
Post Combustion Capture	Coal-Fired Power Plant	Utilities-Electric Power Generation	221110	3.5	8	No
CO_2 Compression and Transportation	Coal-Fired Power Plant	Utilities-Electric Power Generation	221110	3.5	8	No
		Pipeline Transportation of Natural Gas	486200	2.4	3	Yes Natural Gas Liquids (NGLs) in a CO_2 separation facility
Coal Seam Sequestration	Existing Coal Bed Methane recovery	Crude petroleum and natural gas	211111	1.7	16	Depends on the specific configuration
		Drilling Oil and Gas Wells	213111	4.0	26	
Saline Formation Injection	None	NA	NA	NA	NA	Depends on the specific configuration
		Drilling Oil and Gas Wells	213111	4.0	26	

Project	Primary Existing Facility	Industry Category	Industry Code (NAICS Code (1))	Incidence rates(2) of nonfatal occupational injuries and illnesses	Occupational fatalities in 2003	Risk Management Plan Required for use of Extremely Hazardous Materials (Compounds that trigger preparation of an RMP)
Enhanced Oil Recovery	Oil Well Field	Crude petroleum and natural gas	211111	1.7	16	Depends on the specific configuration
		Drilling Oil and Gas Wells	213111	4.0	26	
Terrestrial Sequestration-Reforestation	None	NA	NA	NA	NA	NA
Co-Sequestration of H_2S and CO_2 (from sour gas fields)	Oil or Gas Well Field	Crude Petroleum and natural gas	221110	3.5	8	No
		Drilling Oil and Gas Wells	213111	4.0	26	
Co-Sequestration of H_2S and CO_2 (from IGCC Plants)	Integrated Gasification Combined Cycle Plant	Utilities-Electric Power Generation	221110	3.5	8	No
		Drilling Oil and Gas Wells	213111	4.0	26	
U.S. Average – Private Industry				2.8		

1. North American Industry Classification System
2. The accident incidence rates represent the number of injuries and illnesses per 100 full-time workers and were calculated as: (N/EH) x 200,000, where
N = number of injuries and illnesses, EH = total hours worked by all employees during the calendar year
200,000= base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year)

Source: U.S. Bureau of Labor Statistics, 2005 and U.S. Bureau of Labor Statistics, 2005a.

The types of health risks posed to workers by the assumed existing projects are generally those that are common to the industries that they represent. It is assumed that personnel protective equipment is used by workers at those facilities commensurate with the types of hazards that are present. For example, workers who work near equipment that generate dust would wear a respirator or dust mask as appropriate. The projects are also assumed to comply with applicable guidance of the Occupational Health and Safety Administration (Occupational Safety and Health Standards 29 CFR 1910).

3.10.2 Safety Data for Each State

This section describes the occupational injury rates and occupational fatality data for the 50 states. Occupational injury rates for private industry (2003) and numbers of occupational fatalities (2004) are summarized in Table 3-24.

Table 3-24. Occupational Injury and Fatality Rates by State

State	Occupational Injury Rate (2003)[1]	Occupational Fatalities by State (2004)[2]
Alabama	4.6	133
Alaska	7.0	42
Arizona	4.6	84
Arkansas	5.1	70
California	5.4	467
Colorado	NA	117
Connecticut	5.1	54
Delaware	4.3	10
District of Columbia	NA	11
Florida	5.0	422
Georgia	4.3	232
Hawaii	5.4	25
Idaho	NA	38
Illinois	4.6	208
Indiana	6.2	153
Iowa	6.7	82
Kansas	5.5	80
Kentucky	6.4	143
Louisiana	3.6	121
Maine	7.7	16
Maryland	4.1	81
Massachusetts	NA	72
Michigan	6.3	127
Minnesota	5.5	80
Mississippi	NA	88
Missouri	5.0	165
Montana	7.6	39
Nebraska	5.9	46
Nevada	5.7	61
New Hampshire	NA	15
New Jersey	4.2	129
New Mexico	6.1	57
New York	3.1	254
North Carolina	4.0	183
North Dakota	NA	24
Ohio	NA	202
Oklahoma	5.0	91
Oregon	5.6	60
Pennsylvania	NA	230
Rhode Island	5.4	7
South Carolina	4.4	113
South Dakota	NA	24
Tennessee	5.4	145
Texas	4.0	440
Utah	5.6	50
Vermont	5.2	7
Virginia	4.0	171

State	Occupational Injury Rate (2003)[1]	Occupational Fatalities by State (2004)[2]
Washington	6.8	98
West Virginia	6.1	58
Wisconsin	6.5	94
Wyoming	6.0	43

NA = data not available
Source: [1]U.S. Bureau of Labor Statistics, 2005; [2]U.S. Bureau of Labor Statistics, 2005b.

3.10.3 Other Health and Safety Considerations

The main health and safety risk in the direct use of CO_2 can result in large releases or releases in confined areas that can displace oxygen content in the air. This oxygen displacement can result in oxygen deprivation or death by suffocation. This is a significant safety risk in any operation where compressed CO_2 is used in very large quantities. If accidentally released into a confined space, such as an unventilated room or a large tank, CO_2 presents an odorless and invisible hazard to unsuspecting workers. Release of CO_2 to the atmosphere from geologic features is a process that occurs in nature. Large naturally occurring CO_2 releases are uncommon and have produced variable consequences. Two cases are noteworthy, Lake Nyos in Western Africa and Mammoth Mountain in California. Both Lake Nyos and Mammoth Mountain are atop current or former volcanoes and the release of CO_2 is volcanic in origin (DOE 2005a).

3.10.3.1 Lake Nyos CO_2 Release

Located in the west-African country of Cameroon, Lake Nyos is a few square kilometers in area and 200 meters (m) deep. It is situated in the crater formed from the collapse of the rock channel feeding a now extinct volcano. The lake is compositionally stratified, with fresh water in the upper 50 m and heavier sodium and carbon dioxide rich water below that. The water below 180 m is particularly rich in sodium and carbon dioxide. Most of the sodium and carbon dioxide come from numerous sodium-bicarbonate bearing springs - derived from an underlying magma chamber - feeding into the bottom of the lake.

In August of 1986 some event – perhaps a mudslide, heavy rain or wind blowing across the lake – caused the water column to be disturbed. Some of the deep carbon dioxide rich water moved towards the surface where it was subjected to lower pressure. The dissolved carbon dioxide quickly converted to carbon dioxide gas and rushed to the surface starting a chain reaction of degassing the deeper water. A huge cloud of carbon dioxide spilled over the lake's outlet and down into the surrounding valleys. Thousands of animals and 1700 people died, many in their sleep.

The lake is now degassed in a controlled way to prevent a reoccurrence. The procedure involves lowering a strong polyethylene pipe to the lake bottom. Some water is pumped out at the top, and as the deep water rises through the pipe the carbon dioxide starts to bubble out. The gas and water then become buoyant and suck more water in at the bottom in a self-sustaining process (DOE, 2005).

3.10.3.2 Mammoth Mountain CO_2 Release

Numerous small earthquakes occurred beneath Mammoth Mountain in California between May and November of 1989. Data collected from monitoring instruments during those months indicated that a small body of magma was rising through a fissure beneath the mountain. In the following year, U.S. Forest Service rangers noticed areas of dead and dying trees on the mountain. After drought and insect infestations were eliminated as causes, USGS scientists discovered that the roots of the trees were being killed by exceptionally high concentrations of CO_2 gas in the soil. Although trees produce oxygen (O_2)

from CO_2 during photosynthesis, their roots need to absorb O_2 directly. High CO_2 concentrations in the soil kill plants by denying their roots O_2 and by interfering with nutrient uptake. In the areas of tree kill at Mammoth Mountain, CO_2 makes up about 20 to 95 percent of the gas content of the soil; there is less than 1 percent CO_2 in soils outside the tree-kill areas. Today areas of dead and dying trees at Mammoth Mountain total more than 170 acres, with a total CO_2 flux of roughly 300 tons per day.

It is important to note that neither of the CO_2 release examples are from engineered CO_2 storage facilities. However, the consequences of the large, rapid releases of CO_2 can be dramatic and devastating to humans and the environment (DOE, 2005).

Carbon sequestration projects (other than terrestrial) tend to include large industrial facilities that can include machinery or other components that can pose health and safety risks to workers and the public should one of the processes malfunction. Under normal operating conditions the health and safety risks would be minimal. Malfunctions of project components, such as gas compressor units and liquid ammonia tanks for chillers, or the unsafe storage and handling of chemicals used in various gas treatment processes can pose health and safety hazards. Facilities must review health and safety regulations to determine if they are subject to preparation of a RMP. Certain oil and gas processing plants must prepare RMPs due to their use of large quantities of extremely toxic materials in the facility. An RMP is a requirement of the Chemical Accident Prevention Rule under the CAA Amendments of 1990 [42 U.S.C. s/s 7401 et seq., (1990)]. Whether or not a facility must prepare an RMP is determined by the amounts of materials used at the facility that are listed in the "List of Regulated Substances and Thresholds for Accidental Release Prevention" (40 CFR 9 and 68). Currently there are about 70 facilities in the U.S. that have RMPs where CO_2 is a major process stream. Some of these facilities are compressor stations for CO_2 pipelines that carry CO_2 to enhanced oil recovery operations. Other facilities include gas processing plants that separate various gas or liquid components that occur in a natural gas stream from a well head.

Co-locating a carbon sequestration facility with an existing facility may present a somewhat higher level of health and safety risk than if the two facilities were located separate from each other. This is due to the possibility that the risks of the two facilities together could be greater than the sum of two separate accident or release scenarios. An example is a fire and explosion at one facility that could be large enough to create a secondary explosion at the collocated facility. The EPCRA rules direct that an Offsite Consequence Analysis be performed if certain facility hazard conditions are present to help assist emergency responders in preparing for a potential emergency situation at the facility.

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3.11 SOCIOECONOMICS

This section describes socioeconomic conditions that may be affected by carbon sequestration projects.

As summarized in Table 3-25, the total population of the U.S. is approximately 294 million persons, of which minorities comprise approximately 31 percent. In the 2000 decennial census, 12.4 percent of individuals had incomes below the poverty level. The national population in 2000 had a median age of 35.3 years and an average family size of 3.14 persons.

The national population grew by slightly more than 13 percent in the ten years between 1990 and 2000, while the minority population increased by 43 percent. In the 1990 decennial census, 13.1 percent of individuals had incomes below the poverty level, but the number of individuals in poverty increased by 6.8 percent from 1989 to 1999. The median age of the population in 1990 was 32.9 years and the average family size was 3.16 persons. These comparisons indicate that the proportion of minorities in the U.S. is increasing, the general population is aging, families are becoming smaller, and the poverty rate is declining, but the number of individuals in poverty is increasing.

Table 3-25. Demographics of the U.S.

Jurisdiction	Population	Growth Rate (1990-2000)	Percent Minorities	Individual Poverty Rate	Median Age	Average Family Size
United States	293,655,404	13.2%	30.7%	12.4%	35.3	3.14

Note: Population estimate for mid-2004; all other data from 2000 census.
Minorities include Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Pacific Islander, and Hispanic or Latino, as well as two or more races; excluded are White alone or Some Other Race alone.

Source: U.S. Census Bureau, 2005.

Table 3-26 summarizes housing characteristics in the U.S. The nation added a total of 13.6 million housing units from 1990 to 2000, yielding a rate of increase (13.3 percent) that matched population growth. However, the proportion of new housing units constructed over the same decade ran a few percentage points higher, which indicates that a substantial decrease in older housing stock occurred. The occupancy rate increased from 90 to 91 percent during the decade, and the proportion of rural housing declined from 25.5 to 22.4 percent. During the 1990s, the median unit value of owner-occupied housing increased by more than 52 percent, while the median gross rent increased by nearly 35 percent.

Table 3-26. Housing Characteristics of the U.S.

Jurisdiction	Total Housing Units	Occupancy Rate	Percent Built since 1990	Percent Rural Housing	Median Unit Value	Median Gross Rent
United States	115,904,641	91.0%	17.0%	22.4%	$119,600	$602

Note: All data from 2000 census

Source: U.S. Census Bureau, 2005.

Table 3-27 summarizes economic characteristics of the U.S. The gross domestic product (GDP) of the nation grew by 4.8 percent in 2003, while in the ten years between 1992 and 2002 the GDP grew by an average annual rate of 6.9 percent. The GDP per capita grew by an average annual rate of 4.6 percent during the same ten-year span, while per capita income increased by an average annual rate of 5 percent between the last two decennial censuses. The unemployment rate at the end of 2004 was 5.4 percent. Over the past 20 years, the average annual unemployment rate in the U.S. has ranged between 4.0 and 7.5 percent.

Table 3-27. Economic Characteristics of the U.S.

Jurisdiction	Gross Domestic Product ($B)	Percent Change 2002-03	GDP Per Capita	Revenue Per Capita	Revenue: Expenditure Ratio	Income Per Capita	Unemploy -ment Rate	Res. Elec. Bill (Avg. mo.)
United States	$10,911	4.8%	$37,520	$3,820	0.86	$21,587	5.4%	$76.74

Note: Gross product data for 2003; revenue data for 2002; income per capita for 1999; unemployment rate for December 2004; avg. monthly electric bill for 2002.

Source: U.S. Census Bureau, 2005 and 2004; U.S. BEA, 2005; U.S. BLS, 2005; EIA, 2002.

The average monthly electric bills in 2002 were $76.74 for residential customers, $478.41 for commercial customers and $6,647.01 for industrial customers. Average revenues per Kilowatt hour were 8.46, 7.86, and 4.88 cents, respectively, for residential, commercial, and industrial customers (EIA, 2002).

Information concerning demographics, housing characteristics, and economic characteristics for each state is provided in Table 3-28 through Table 3-30.

Table 3-28. Demographics of the States

Jurisdiction	Population	Growth Rate (1990-2000)	Percent Minorities	Individual Poverty Rate	Median Age	Average Household Size
Alabama	4,447,100	10.1	29.0	17	37.4	2.49
Alaska	626,932	14.0	30.8	11.2	33.9	2.74
Arizona	5,130,632	40.0	23.8	14.2	34.5	2.64
Arkansas	2,673,400	13.7	21.0	17.2	37.0	2.49
California	33,871,648	13.8	39.1	13.3	34.4	2.87
Colorado	4,301,261	30.6	16.5	11.1	34.7	2.53
Connecticut	3,405,565	3.6	18.8	8.3	39.3	2.53
Delaware	783,600	17.6	26.4	10.4	37.9	2.54
District of Columbia	572,059	-5.7	67.6	19	35.9	2.16
Florida	15,982,378	23.5	23.2	12.8	39.5	2.46
Georgia	8,186,453	26.4	37.5	14.4	34.3	2.65
Hawaii	1,211,537	9.3	75.7	9.8	38.5	2.92
Idaho	1,293,953	28.5	8.2	13.9	34.6	2.69
Illinois	12,419,293	8.6	27.8	12	35.6	2.63
Indiana	6,080,485	9.7	13.9	12.2	36.1	2.53
Iowa	2,926,324	5.4	6.5	10.9	38.6	2.46
Kansas	2,688,418	8.5	14.8	11.7	36.1	2.51
Kentucky	4,041,769	9.7	10.1	16.8	37.5	2.47
Louisiana	4,4468,976	5.9	36.3	19.8	35.4	2.62
Maine	1,274,923	3.8	3.4	12.6	41.2	2.39
Maryland	5,296,486	10.8	38.5	8.2	37.1	2.61
Massachusetts	6,349,097	5.5	16.6	10.3	38.2	2.51
Michigan	9,938,440	6.9	20.0	13.2	36.9	2.56
Minnesota	4,919,479	12.4	12.0	9.2	36.7	2.52
Mississippi	2,844,658	10.5	39.2	21.3	35.5	2.63

Jurisdiction	Population	Growth Rate (1990-2000)	Percent Minorities	Individual Poverty Rate	Median Age	Average Household Size
Missouri	5,595,211	9.3	15.5	13.3	37.4	2.48
Montana	902,195	12.9	9.4	14.4	40.2	2.45
Nebraska	1,711,263	8.4	10.4	10.9	36.2	2.49
Nevada	1,998,257	66.3	23.9	11.1	35.2	2.62
New Hampshire	1,235,786	11.4	4.5	7.5	39.5	2.53
New Jersey	8,414,350	8.9	30.1	8.7	38	2.68
New Mexico	1,819,046	20.1	30.5	18.5	36.2	2.63
New York	18,976,457	5.5	32.9	13.8	37.5	2.61
North Carolina	8,049,313	21.4	28.6	15.1	36.2	2.49
North Dakota	642,200	0.5	8.5	11.2	39.1	2.41
Ohio	11,353,140	4.7	15.7	13	37.6	2.49
Oklahoma	3,450,654	9.7	24.6	16.5	36.5	2.49
Oregon	3,421,399	20.4	13.2	14.1	37	2.51
Pennsylvania	12,281,054	3.4	15.4	11.9	39.7	2.48
Rhode Island	1,048,319	4.5	17.1	12.3	38.4	2.47
South Carolina	4,012,012	15.1	32.6	15.6	37.1	2.53
South Dakota	754,844	8.5	12.0	13.6	37	2.50
Tennessee	5,689,283	16.7	20.4	15.5	37.3	2.48
Texas	20,851,820	22.8	28.1	17.6	33.2	2.74
Utah	2,233,169	29.6	10.2	10.2	28.5	3.13
Vermont	608,827	8.2	3.4	11.5	40.7	2.44
Virginia	7,078,515	14.4	28.3	10	37.2	2.54
Washington	5,894,121	21.1	18.8	11.9	36.7	2.53
West Virginia	1,808,344	0.8	5.0	18	40.7	2.40
Wisconsin	5,363,675	9.6	11.9	10.2	37.9	2.50
Wyoming	493,782	8.9	7.6	9.5	39.1	2.48

Note: All data from 2000 census
Source: U.S. Census Bureau, 2005.

Table 3-29. Housing Characteristics of the States

Jurisdiction	Total Housing Units	Occupancy Rate (%)	Percent Built since 1990	Percent Rural Housing	Median Housing Value ($)	Median Gross Rent ($)
Alabama	1,963,711	88.5	22.6	44.6	97,500	535
Alaska	260,978	84.9	18.0	34.3	197,100	832
Arizona	2,189,189	86.8	29.3	11.8	185,400	717
Arkansas	1,173,043	88.9	22.1	47.6	87,400	549
California	12,214,549	94.2	12.9	5.5	477,700	973
Colorado	1,808,037	91.7	22.1	15.5	223,300	757
Connecticut	1,385,975	93.9	8.6	12.3	271,500	839
Delaware	343,072	87.0	21.2	19.9	203,800	793
District of Columbia	274,845	90.4	2.6	0.0	384,400	832
Florida	7,302,947	86.8	22.7	10.7	189,500	809
Georgia	3,281,737	91.6	27.9	28.3	147,500	709
Hawaii	460,542	87.6	18.1	8.5	272,700	779
Idaho	527,824	89.0	25.4	33.7	134,900	594
Illinois	4,885,615	94.0	12.4	12.1	183,900	734
Indiana	2,532,319	92.3	17.3	29.2	114,400	615
Iowa	1,232,511	93.2	12.3	38.9	106,600	559
Kansas	1,131,200	91.8	14.6	28.6	107,800	588
Kentucky	1,750,927	90.8	21.2	44.3	103,900	527
Louisiana	1,847,181	89.6	14.6	27.3	101,700	569
Maine	651,901	79.5	14.6	59.8	155,300	623
Maryland	2,145,283	92.3	16.7	13.9	280,200	891
Massachusetts	2,621,989	93.2	8.3	8.6	361,500	902
Michigan	4,234,279	89.4	14.7	25.4	149,300	655
Minnesota	2,065,946	91.7	16.1	29.1	198,800	692
Mississippi	1,161,953	90.0	22.1	51.2	82,700	538
Missouri	2,442,017	89.9	17.0	30.6	123,100	593
Montana	412,633	86.9	17.6	45.9	131,600	552
Nebraska	722,668	92.2	13.5	30.3	113,200	569
Nevada	827,457	90.8	42.4	8.4	283,400	861
New Hampshire	547,024	86.8	13.4	40.8	240,100	854
New Jersey	3,310,2785	92.6	10.5	5.65	333,900	935
New Mexico	780,579	86.9	22.9	25.0	125,500	587
New York	7,679,307	91.9	6.8	12.5	258,900	841
North Carolina	3,523,944	88.9	27.0	39.8	127,600	635
North Dakota	289,677	88.8	13.0	44.2	88,600	479
Ohio	4,783,051	92.9	13.3	22.7	129,600	613
Oklahoma	1,514,400	88.6	13.4	34.7	89,100	547
Oregon	1,452,709	91.8	21.9	21.3	201,200	689
Pennsylvania	5,249,750	91.0	10.4	23.0	131,900	647

Jurisdiction	Total Housing Units	Occupancy Rate (%)	Percent Built since 1990	Percent Rural Housing	Median Housing Value ($)	Median Gross Rent ($)
Rhode Island	439,837	92.9	8.7	9.0	281,300	775
South Carolina	1,753,670	87.5	25.9	39.5	113,100	611
South Dakota	323,208	89.8	16.2	48.1	101,700	500
Tennessee	2,439,443	91.5	23.5	36.3	114,000	583
Texas	8,157,575	90.6	20.7	17.5	106,000	671
Utah	768,594	91.2	25.9	11.7	167,200	665
Vermont	294,382	81.7	13.7	61.80	173,400	683
Virginia	2,904,192	92.9	20.0	27.0	212,300	812
Washington	2,451,075	92.7	21.7	18.0	227,700	741
West Virginia	844,623	87.2	15.5	53.9	84,400	483
Wisconsin	2,321,144	89.8	16.8	31.7	152,600	643
Wyoming	223,854	86.5	13.9	34.8	135,000	537

Note: All data from 2000 census
Source: U.S. Census Bureau, 2005.

Table 3-30. Economic Characteristics of the States

Jurisdiction	Gross State Product ($B)	Percent Change 2004-05	GSP Per Capita ($)	State Revenue Per Capita ($)	Revenue: Expenditure Ratio	Income Per Capita ($)	Unemploy-ment Rate (%)	Res. Elec. Bill ($ Avg. mo.)
Alabama	132	3	29,730	4,766.51	0.91	27,795	4.0	80.34
Alaska	31	0.5	47,657	13,453.17	0.91	34,454	6.8	91.17
Arizona	182	8.7	38,548	4,143.63	0.91	28,442	4.7	77.05
Arkansas	75	2.5	28,772	5,172.79	0.89	25,725	4.9	89.10
California	1,446	4.3	43,430	6,397.23	0.89	35,019	5.4	66.47
Colorado	187	4.1	44,787	5,015.63	0.78	36,063	5.0	55.69
Connecticut	173	3.7	50,816	5,578.38	1.00	45,398	4.9	88.42
Delaware	47	1.3	60,764	6,864.88	0.95	35,861	4.2	60.46
District of Columbia	70	4.5	12,2972	4,333.11	0.80	51,803	6.5	84.02
Florida	550	7.8	37,281	3,903.82	0.98	31,455	3.8	104.50
Georgia	320	4.5	39,999	5,098.47	0.81	30,051	5.3	84.47
Hawaii	46	4.8	37,968	4,752.00	0.95	32,160	2.8	109.41
Idaho	40	7.4	33,648	4,623.84	0.90	27,098	3.8	71.60
Illinois	499	2.1	40,216	4,322.69	0.94	34,351	5.7	63.93
Indiana	214	1.1	35,210	5,202.51	0.87	30,094	5.4	61.49
Iowa	103	1.7	34,700	4,039.56	1.01	30,560	4.6	68.45
Kansas	93	4.0	34,476	4,900.06	0.99	30,811	5.1	68.82
Kentucky	129	2.2	30,812	5,201.03	0.87	27,709	6.1	65.09
Louisiana	140	-2.0	30,289	6,319.34	0.88	27,581	7.1	100.17
Maine	39	1.0	31,171	5,108.57	0.89	30,566	4.8	75.03
Maryland	212	3.7	40,817	6,495.36	0.92	39,247	4.1	83.34

Jurisdiction	Gross State Product ($B)	Percent Change 2004-05	GSP Per Capita ($)	State Revenue Per Capita ($)	Revenue: Expenditure Ratio	Income Per Capita ($)	Unemploy-ment Rate (%)	Res. Elec. Bill ($ Avg. mo.)
Massachusetts	299	2.6	47,250	5,547.07	0.94	41,801	4.8	66.10
Michigan	365	0	34,478	5,828.57	0.97	31,954	6.7	55.50
Minnesota	211	1.3	42,673	5,291.65	0.93	35,861	4.0	61.09
Mississippi	72	1.2	24,492	4,569.52	0.84	24,650	7.9	71.30
Missouri	195	2.1	34,358	5,881.00	0.86	30,608	5.4	92.56
Montana	26	5.4	28,242	4,757.71	0.84	26,857	4.1	61.49
Nebraska	66	1.7	36,105	4,344.68	0.86	31,339	3.8	90.56
Nevada	88	8.2	48,335	4,753.39	0.92	33,405	4.1	67.08
New Hampshire	50	4.4	41,006	5,825.37	0.92	37,040	3.6	67.10
New Jersey	385	2.1	45,814	6,205.85	0.93	41,332	4.4	75.35
New Mexico	56	4.6	32,910	7,080.59	0.97	26,191	5.3	74.69
New York	867	3.3	45,692	5,195.69	0.84	38,228	5.0	51.26
North Carolina	314	3.9	38,314	8,220.21	0.61	29,246	5.2	87.15
North Dakota	21	4.6	32,512	6,676.28	0.77	31,398	3.9	81.72
Ohio	403	1.0	34,786	4,971.72	0.85	31,322	5.9	70.71
Oklahoma	100	2.9	29,209	6,819.47	0.77	28,089	4.4	80.76
Oregon	120	6.7	39,931	5,584.37	0.83	29,971	6.1	69.64
Pennsylvania	450	2.1	35,039	6,727.96	0.88	33,348	5.0	80.68
Rhode Island	38	2.0	36,777	5,060.02	1.01	33,733	5.0	68.88
South Carolina	127	3.5	30,993	5,011.18	0.77	27,172	6.8	94.45
South Dakota	27	3.5	36,657	4,059.19	0.93	30,856	3.9	69.17
Tennessee	200	1.6	35,697	4,030.37	0.85	30,005	5.6	82.60
Texas	813	4.3	40,549	5,439.01	0.82	30,222	5.3	109.02
Utah	76	5.8	35,451	6,928.49	0.91	26,606	4.3	50.69
Vermont	21	3.0	34,662	4,777.41	0.85	32,770	3.5	90.45
Virginia	304	5.6	44,372	5,652.64	0.93	35,477	3.5	78.34
Washington	245	3.7	40,597	6,416.63	0.85	35,299	5.5	65.61
West Virginia	47	3.2	25,272	6,314.18	0.82	25,872	5.0	63.14
Wisconsin	200	2.0	36,260	10,181.77	0.70	32,157	4.7	65.18
Wyoming	22	4.9	41,830	4,766.51	0.91	34,306	3.6	57.76

Note: All data from 2000 census

Source: U.S. Census Bureau, 2005 and 2004; U.S. BEA, 2005; U.S. BLS, 2005; EIA, 2002.

3.12 UTILITY INFRASTRUCTURE

This section describes the utility infrastructure that may be affected by carbon sequestration projects. It includes current and projected future growth in electricity transmission lines and natural gas transmission and distribution lines in the U.S. The distribution of wastewater treatment facilities at a national level is also discussed. The utility rights-of-way afforded by this infrastructure can serve as possible corridors for the installation of CO_2 pipelines that may be required to implement one or more carbon capture and sequestration technology projects.

3.12.1 Electricity Transmission Lines

The North American Electric Reliability Council (NERC) through its ten regional councils ensures the reliability of the North American electricity transmission system. Figure 3-29 shows the geographic areas covered by the ten NERC regional councils whose members account for virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, Mexico. In addition to the ten regional councils, the Alaska Systems Coordinating Council (ASCC), which covers the state of Alaska, is an affiliate NERC member.

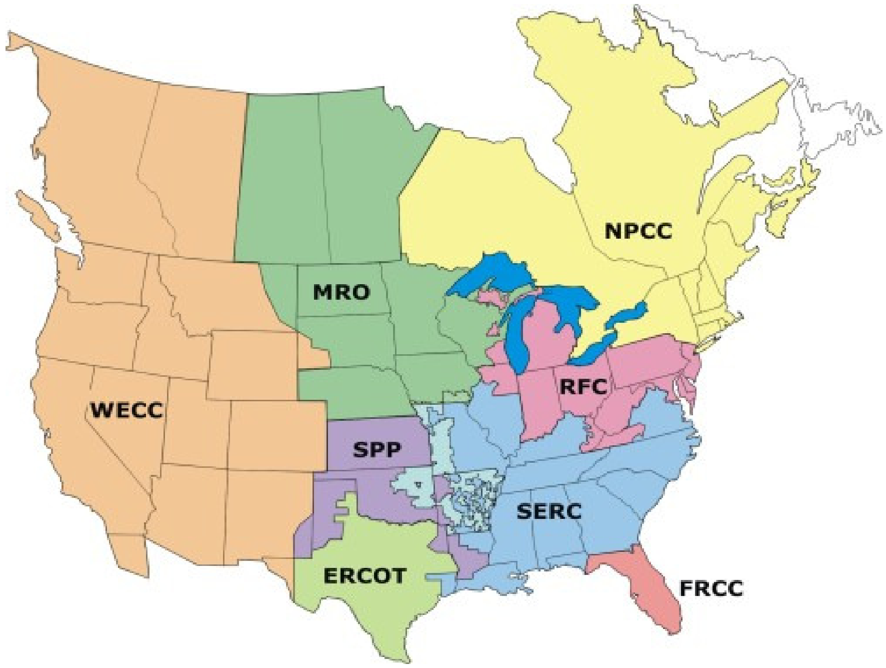
A breakdown of the total miles of high voltage (230 kV and greater) electricity transmission lines by NERC regions is shown in Table 3-31 (NERC, 2004, Alaska Energy Taskforce, 2003). A projection of planned increases is also included in the table. As of 2003, there were a total of 209,000 circuit miles within the NERC regions in the U.S., Canada, and Mexico. This includes about 161,000 miles spread across the 48 U.S. contiguous states and Alaska. More than 5,600 miles of new transmission (230 kV and above) are proposed for addition through 2008, with a total of about 10,325 miles added over the 2004–2013 timeframe. This represents a 5 percent increase in the total installed circuit miles of high voltage transmission lines in North America.

Table 3-31. Current and Planned High Voltage Transmission Circuit Miles in NERC Regions

NERC -Region	2003 Existing	2004–2008 Planned Additions	2009–2013 Planned Additions	2013 Total Projected
ASCC	760	NA[1]	NA[1]	760
ECAR	16,439	156	17	16,612
ERCOT	8,081	290	110	8,481
FRCC	6,894	360	81	7,335
MAAC	7,057	134	0	7,191
MAIN	6,195	374	260	6,829
MRO-U.S.	14,705	228	246	15,179
NPCC-U.S.	6,406	376	0	6,782
SERC	28,868	1,349	1,085	31,302
SPP	7,659	191	17	7,867
WECC-U.S.	58,400	1,573	1,582	61,555
Total U.S.	161,464	5,031	3,398	169,893
MRO-Canada	6,660	94	963	7,717
NPCC-Canada	28,961	258	38	29,257
WECC-Canada	10,969	270	252	11,491
Total Canada	46,590	622	1,253	48,465
WECC-Mexico	563	24	0	587
TOTAL NERC	208,617	5,677	4,651	218,945

[1] *NA=Not Available*

Source: NERC, 2004; Alaska Energy Taskforce, 2003.



Key:
ECAR – East Central Area Reliability Coordination Agreement
ERCOT – Electric Reliability Council of Texas, Inc.
FRCC – Florida Reliability Coordinating Council
MAAC – Mid-Atlantic Area Council
MAIN – Mid-America Interconnected Network, Inc.
MRO – Midwest Reliability Organization
NPCC – Northeast Power Coordinating Council
SERC – Southeastern Electric Reliability Council
SPP – Southwest Power Pool, Inc.
WECC – Western Electricity Coordinating Council

Source: NERC, 2007.

Figure 3-29. Map of NERC's Regional Reliability Councils.

3.12.2 Natural Gas Pipelines

Based on statistical data for 2003 from the Office of Pipeline Safety (OPS), there are about 2.2 million miles of pipelines in natural gas transmission and distribution service in the U.S. A breakdown of the total mileage in gas transmission and distribution is shown in Table 3-32.

Table 3-32. Breakdown of Total Miles of Natural Gas Pipelines by Service Type in 2003

Service Type	United States
Gas Transmission	304,001
Gas Distribution (Main)	1,097,910
Gas Distribution (Service)	754,361
TOTAL	2,156,272

Source: DOT, 2005.

Based on projected demand for natural gas in North America, about 45,000 miles of pipe will be required over the 2003 – 2020 time period. Approximately 35,000 miles will be new pipe while 10,000 miles will be needed to replace existing pipe. Of the 35,000 miles of new pipe, approximately 7,000 miles will be associated with bringing Alaskan and MacKenzie Delta gas to the lower 48 states. Approximately two-thirds of anticipated pipeline capacity built will be less than 24 inches in diameter. Such pipe will most likely be used to relieve local bottlenecks, connect new industrial customers, connect new power plants, or access new supply within a basin (INGAA, 2004). These new pipeline additions represent additional opportunities for utility rights-of-way that will be required for developing CO_2 pipeline infrastructure.

Table 3-33 provides information on natural gas pipelines in each state.

Table 3-33. Estimated Miles of Natural Gas Transmission in the Lower 48 States, 2004

State	Transmission Pipeline Mileage
Alabama	4,687
Arizona	5,989
Arkansas	6,201
California	11,669
Colorado	7,186
Connecticut	619
Delaware	231
Florida	4,636
Georgia	3,342
Idaho	1,567
Illinois	11,904
Indiana	4,679
Iowa	5,347
Kansas	15,251
Kentucky	6,776
Louisiana	18,155
Maine	607
Maryland/District of Columbia	959
Massachusetts	934
Michigan	9,688
Minnesota	4,431
Mississippi	9,484
Missouri	3,769
Montana	3,861
Nebraska	5,346
Nevada	1,465
New Hampshire	291
New Jersey	1,512
New York	4,726
New Mexico	6,628
North Carolina	2,474
North Dakota	1,873
Ohio	7,,612
Oklahoma	18394
Oregon	1,823
Pennsylvania	8,522
Rhode Island	100
South Carolina	2,265

State	Transmission Pipeline Mileage
South Dakota	1,242
Tennessee	4,273
Texas	59,109
Utah	3,016
Vermont	53
Virginia	2,428
Washington	2,070
West Virginia	4,729
Wisconsin	3,308
Wyoming	7,090
Total	**24,583**

Source: Tobin, 2005.

3.12.3 CO_2 Pipelines

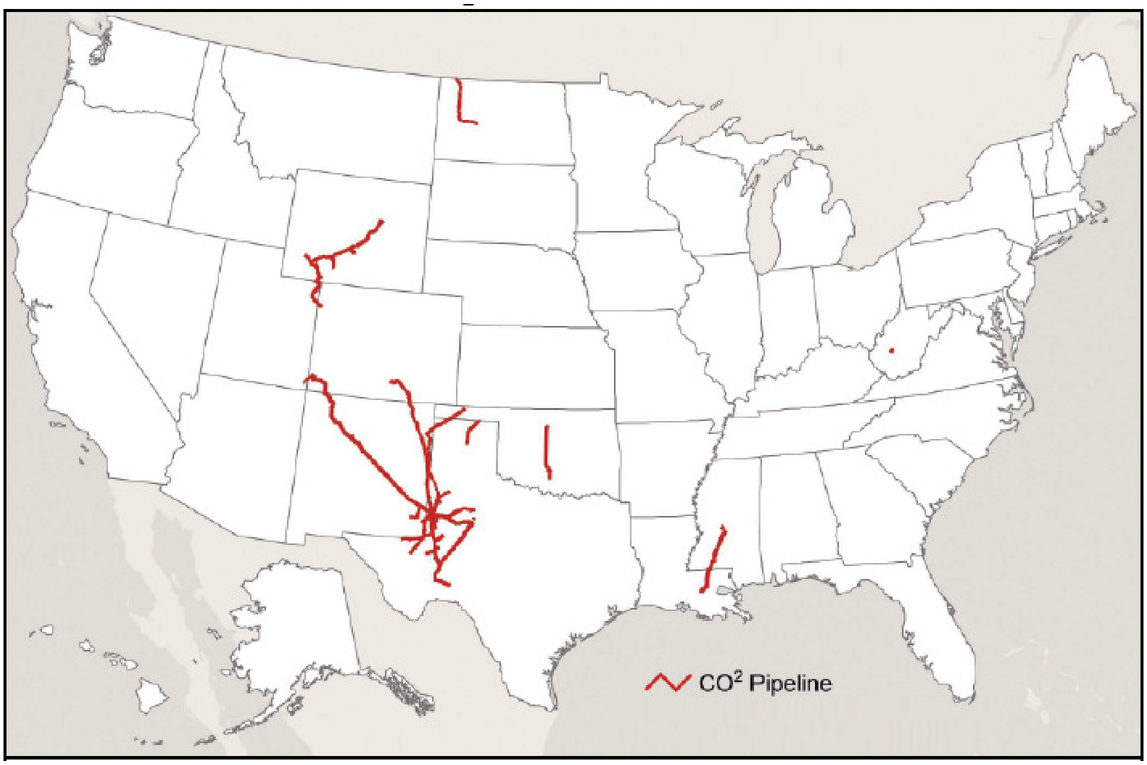
A list of major CO_2 pipelines currently being operated in the U.S. is shown in Table 3-34 and in Figure 3-30. There are almost 3,300 miles of CO_2 pipelines that are currently used to deliver CO_2 to EOR sites in the U.S. and Canada. The larger CO_2 pipeline networks deliver naturally occurring CO_2 from underground-sources at McElmo Dome and Sheep Mountain in Colorado, Bravo Dome in New Mexico, and Jackson Dome in Mississippi to EOR sites located in Texas, Oklahoma, New Mexico, Utah, Mississippi, and Louisiana. A smaller network connects sources of anthropogenic CO_2 obtained from gas processing facilities to EOR sites in Oklahoma, Texas, Wyoming, and Canada.

Table 3-34. Major CO_2 Pipelines in the United States

Name	Operator	Route	Length (miles)	Diameter (in.)
Anadarko pipeline extension	Anadarko	Baroil to Salt Creek, WY	125	16
Anton Irish	Oxy	Denver City to Anton Irish Field, TX	40	8
Bravo pipeline	BP	Bravo Dome, NM to Denver City, TX	218	20
Canyon Reef Carriers (CRC) pipeline	Kinder Morgan	McCamey to SACROC, TX	140	16
Comanche Creek	Kinder Morgan	Crane County to CBPL, TX	90	6
Centerline Pipeline	Kinder Morgan	Denver City to SACROC, TX	113	16
Central Basin pipeline (CBPL)	Kinder Morgan	Denver City Hub to McCamey, TX	140	26, 16
Chaparral	Chaparral Energy	Lateral off Transpetco line to Morrow fields, OK	23	6
Choctaw pipeline	Denbury Resources	Jackson Dome, MS to Bayou Choctaw field, LA	183	20
Cordona Lake	ExxonMobil	Lateral from CBPL to Cordona Lake, TX	7	6
Cortez pipeline	Kinder Morgan	McElmo Dome, CO to Denver City, TX	502	30
Dollarhide	Pure Energy	Lateral from CBPL to Dollarhide, TX	23	8
El Mar	KinderMorgan	Lateral between Dollarhide and El Mar, TX	35	6
Enid-Lindsey pipeline	Anadarko	Enid to Lindsey, OK	120	8
Este pipeline	Exxon Mobil	Denver City to Salt Creek, TX	119	12, 14
Exxon Wyoming CO_2 pipeline	Exxon Mobil	Shute Creek pipeline interconnect to Rock Springs and Baroil, WY	112	16, 20
Ford	KinderMorgan	Lateral between El Mar and Ford, TX	12	4
Llano Lateral	Trinity Pipeline	Connects Cortez pipeline to Llano, NM	53	12,8

Name	Operator	Route	Length (miles)	Diameter (in.)
McElmo Creek pipeline	Exxon Mobil	McElmo Dome to McElmo Creek, UT	40	8
Pecos County	KinderMorgan	McCamey to Yates field, TX	26	8
Raven Ridge	Chevron Texaco	Rock Springs, WY to Rangely, CO	125	16
Sheep Mountain I pipeline	BP	Sheep Mountain Field to Rosebud connection at Bravo Dome	184	20
Sheep Mountain II pipeline	BP	Rosebud connection to Denver City and onward to Seminole San Andreas Unit, TX	224	24
Shute Creek	ExxonMobil	LaBarge to Exxon Wyoming CO_2 pipeline interconnect.	30	30
Slaughter pipeline	ExxonMobil	Denver City to Hockley County, TX	40	12
Transpetco/Bravo pipeline	Transpetco	Bravo Dome to Postle field, OK	120	12.75
Val Verde pipeline	Petro Source	Connects gas processing facilities to CRC pipeline at McCamey, TX	83	10
Wellman	Wiser	Denver City to Wellman, TX	25	6
White Frost	Core Energy, LLC	Antrim gas plant to Dover field, MI	11	6
West Texas pipeline	Trinity Pipeline	Denver City to Reeves County, TX	127	12, 8
Weyburn pipeline	Dakota Gasification Company	Great Plains Synfuels plant in North Dakota to Weyburn field, Canada	205	14, 12

Source: Kindermorgan.com; Heddle et. al., 2003; IOGCC, 2005.



Source: U.S. DOT-NPMS, 2005

Figure 3-30. Major CO_2 Pipeline Systems in the United States

3.12.4 Water and Wastewater Treatment Facilities

Water and wastewater services in the U.S. are decentralized. There are about 54,000 community water systems that supply most of the nation's drinking water and about 16,000 wastewater treatment systems that provide sewer service. The infrastructure includes about 800,000 miles of water delivery pipelines and 600,000 – 800,000 miles of sewer pipelines. These systems vary in size and distribution. A majority of these utilities are small with 93 percent of community drinking water and 71 percent of wastewater systems serving 10,000 people or fewer (USGAO, 2004).

A breakdown by flow range and state of the total number of wastewater treatment facilities that are currently in operation in the U.S. (Table 3-36) is documented by the EPA (2003) in a Clean Watersheds Needs Survey (CWNS) report that is available at http://www.epa.gov/owm/mtb/cwns/2000rtc/toc.htm. The breakdown by flow range is reproduced in Table 3-36. As of 2000, there were a total of 16,255 wastewater treatment facilities treating about 35 billion gallons per day (gpd) of wastewater in the U.S. About 80 percent of these facilities have flow rates ranging between 1,000 to 1,000,000 gpd with total flow rates of about 2.6 billion gpd (7.5 percent of the U.S. total flow rate). About 19 percent are larger facilities with flow rates ranging between 1 – 100 million gpd and total flow rates of 21 billion gpd (60 percent of U.S. total). Less than 1 percent (about 50) of the total includes the largest facilities with operating flow rates exceeding 100 million gpd and total flow rates of about 11 billion gpd (32 percent of U.S. total).

Table 3-35. Breakdown of Operating Wastewater Treatment Facilities by Flow Range

Flow Range (GPD)	Existing Facilities in 2000		Total Flow	
	Number	Percent of Total	Million GPD	Percent of Total
1,000 to 100,000	6,583	40.5	290	0.8
100,001 to 1,000,000	6,462	39.8	2,339	6.7
1,000,001 to 10,000,000	2,665	16.4	8,328	23.9
10,000,001 to 100,000,000	487	3.0	12,741	36.5
> 100,000,000	46	0.3	11,201	32.1
Other	12	0.1	NA[1]	NA[1]
TOTAL	16,255	100.0	34,899	100.0

[1] *NA= Not Available; Flow data for these facilities were unavailable.*

Source: EPA, 2003.

Table 3-36 provides information on wastewater treatment facilities in each state.

Table 3-36. Breakdown of Wastewater Treatment Facilities in each State

State	Number of Facilities
Alabama	272
Alaska	45
Arizona	118
Arkansas	335
California	586
Colorado	311
Connecticut	91
Delaware	18
District of Columbia	1
Florida	277
Georgia	352
Hawaii	21
Idaho	168
Illinois	721

State	Number of Facilities
Indiana	404
Iowa	726
Kansas	634
Kentucky	224
Louisiana	355
Maine	137
Maryland	156
Massachusetts	126
Michigan	396
Minnesota	514
Mississippi	303
Missouri	678
Montana	194
Nebraska	462
Nevada	51
New Hampshire	85
New Jersey	156
New Mexico	55
New York	588
North Carolina	491
North Dakota	282
Ohio	765
Oklahoma	489
Oregon	207
Pennsylvania	779
Rhode Island	21
South Carolina	186
South Dakota	271
Tennessee	246
Texas	1,363
Utah	97
Vermont	81
Virginia	227
Washington	235
West Virginia	212
Wisconsin	592
Wyoming	96

Source: EPA, 2003.

3.12.5 Transportation

The U.S. transportation system carries over 4.7 trillion passenger miles of travel and 3.7 trillion ton miles of domestic freight generated by about 270 million people, 6.7 million business establishments, and 88,000 units of government. Rail and maritime transportation each account for over 11 percent of the tonnage carried.

Transportation investment and annual expenditures represent a significant element of our overall national assets and expenditures. American households, businesses, and governments spend over $1 trillion to travel 3.8 trillion miles and to ship goods 3.5 trillion miles each year. The net depreciated value of personal motor vehicles alone is $900 billion, and the value of roads and highways is estimated at over

$700 billion. When adjusted to formal definitions of the National Income Product Accounts, transportation accounts for 12 percent of Gross Domestic Product.

Summarized in the following are key aspects of the National Highway System and National Railroad Freight System.

3.12.5.1 National Highway System

On June 29, 1956, President Eisenhower signed the Federal Aid-Highway Act of 1956, which authorized the interstate highway system (later formally named the Dwight D. Eisenhower System of Interstate and Defense Highways). The Act authorized 41,000 miles of high quality highways that were to tie the nation together. Later, congressional action increased the length to 42,500 miles and required super-highway standards for all interstate highways.

The system was to be completed by 1975. It was conceived as a "pay as you go" system that would rely primarily on federally imposed user fees on motor fuels --- the federal user fee per gallon of gasoline was increased by one cent. The federal user fees would provide 90 percent of the cost of construction with the balance provided primarily by state user fees. The interstate highway system would incorporate approximately 2,000 miles of already completed toll roads.

The current National Highway System (NIH) consists of approximately 160,000 miles (256,000 kilometers) of roadway important to the nation's economy, defense, and mobility (Figure 3-31). The NHS includes the following subsystems of roadways (note that a specific highway route may be on more than one subsystem):

- Interstate : The Eisenhower Interstate System of highways retains its separate identity within the NHS.
- Other Principal Arterials: These are highways in rural and urban areas which provide access between an arterial and a major port, airport, public transportation facility, or other intermodal transportation facility.
- Strategic Highway Network (STRAHNET): This is a network of highways which are important to the U.S.' strategic defense policy and which provide defense access, continuity and emergency capabilities for defense purposes.
- Major Strategic Highway Network Connectors: These are highways which provide access between major military installations and highways which are part of the Strategic Highway Network.
- Intermodal Connectors: These highways provide access between major intermodal facilities and the other four subsystems making up the National Highway System.

In addition to being designed to support automobile and heavy truck traffic, interstate highways are also designed for use in military and civil defense operations within the U.S., particularly troop movements. One potential civil defense use of the Interstate highway system is for the emergency evacuation of cities in the event of a potential war. The Interstate Highway System has been used to facilitate evacuations in the face of hurricanes and other natural disasters.

Over 40 corridors have been designated as high priority corridors on the National Highway System (NHS) and are included in the 163,000-mile approved NHS as specific routes or general corridors. (Some of the corridors are part of longer high priority corridors.) Some of the corridors are entirely within a single State; some are multi-State corridors. (e.g., the Sarnia, Ontario, Canada to Lower Rio Grande Valley, Texas, corridor and the Sault Ste. Marie, Michigan, to Charleston, South Carolina, corridor).

Some of these corridors are described in detail in legislation while others are broadly defined. Figure 3-32 is a map showing the location of these high priority corridors.

3.12.5.2 National Railroad Freight System

In 2002, the freight railroad industry produced over 1.5 trillion ton-miles that generated revenue of $36.9 billion. The industry originated over 31 million carloads on a network consisting of nearly 142,000 miles of road. The industry employed over 177,000 employees. Figure 3-33 is a map of the U.S. railroad network.

Freight railroads in the U.S. move 42 percent of our nation's freight (measured in ton-miles) - everything from lumber to vegetables, coal to orange juice, grain to automobiles, and chemicals to scrap iron - and connect businesses with each other across the country and with markets overseas. They also contribute billions of dollars each year to the economy through investments, wages, purchases, and taxes.

There were 554 common carrier freight railroads operating in the U.S. in 2002, classified into five groups. Class I railroads are those with operating revenue of at least $272 million in 2002. Class I carriers comprise only 1 percent of the number of U.S. freight railroads, but they account for 70 percent of the industry's mileage operated, 89 percent of its employees, and 92 percent of its freight revenue. Class I carriers typically operate in many different states and concentrate largely (though not exclusively) on long-haul, high-density intercity traffic lanes. There are seven Class I railroads ranging in size from just over 3,000 to more than 33,000 miles operated and from 2,600 to more than 46,000 employees.

U.S. freight railroads employ approximately 177,000 people, the vast majority of whom are unionized. With average total compensation in 2002 of more than $80,000, freight railroad employees are among the nation's most-highly compensated workers.

By any measure of capital intensity, freight railroads are at or near the top among all major U.S. industries. From 1980 through 2003, Class I railroads spent more than $320 billion approximately 44 percent of their operating revenue - on capital expenditures and maintenance expenses related to infrastructure and equipment. Non-Class I carriers spent billions of dollars more. These massive expenditures help ensure that railroads have the capability to offer high quality, safe, and cost-effective service to meet the freight transportation needs of our nation.

Coal is the most important single commodity carried by rail. In 2002, it accounted for 44 percent of tonnage and 21 percent of revenue for Class I railroads. The vast majority of coal in the U.S. is used to generate electricity at coal-fired power plants. Coal accounts for half of all U.S. electricity generation, far more than any other fuel source, and railroads handle approximately two-thirds of all U.S. coal shipments.

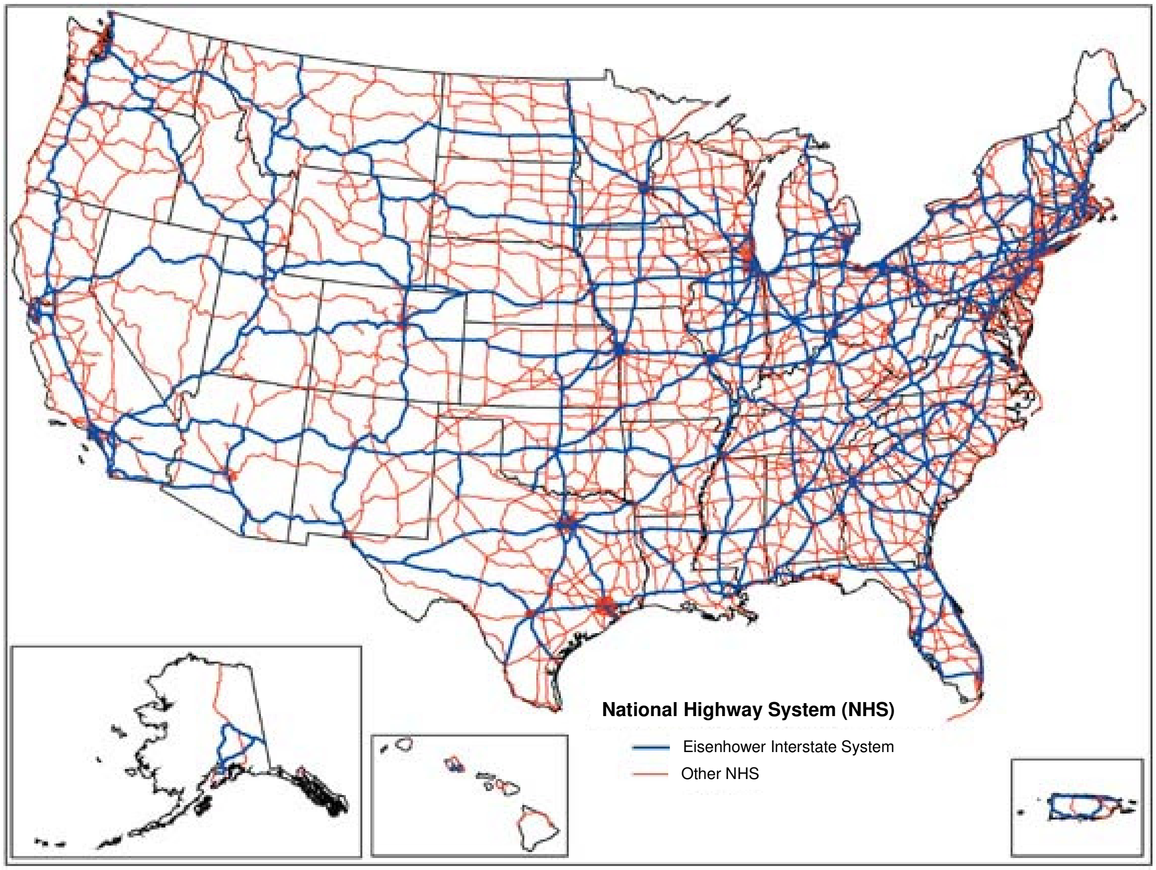
Table 3-37 provides transportation information for each state.

Table 3-37. National Highway System Miles and Rail Line Miles in each State

State	Miles of Highways	Miles of Rail Lines
Alabama	3,707	3,332
Alaska	2,111	506
Arizona	2,743	1,815
Arkansas	2,724	2,692
California	7,630	5,796
Colorado	3,580	2,530
Connecticut	963	543
Delaware	322	228
District of Columbia	83	24
Florida	4,364	2,840
Georgia	4,392	4,779

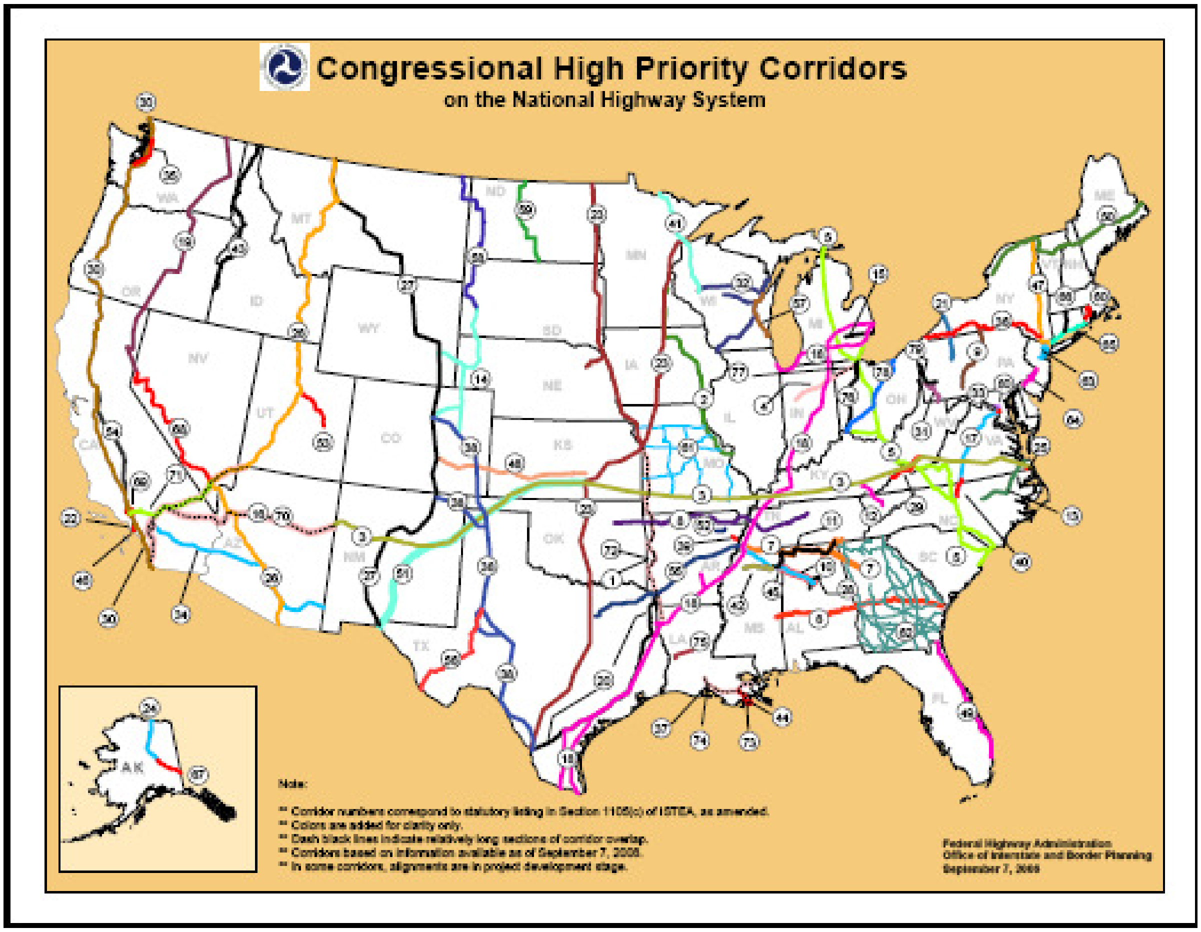
State	Miles of Highways	Miles of Rail Lines
Hawaii	347	0
Idaho	2,369	1,529
Illinois	5,703	7,338
Indiana	2,883	4,192
Iowa	3,216	3,946
Kansas	3,781	4,936
Kentucky	2,891	2,640
Louisiana	2,604	2,971
Maine	1,289	1,148
Maryland	1,457	759
Massachusetts	1,971	1,097
Michigan	4,759	3,590
Minnesota	3,969	4,589
Mississippi	2,823	2,481
Missouri	4,458	4,122
Montana	3,875	3,269
Nebraska	2,985	3,478
Nevada	2,132	1,202
New Hampshire	825	421
New Jersey	2,076	917
New Mexico	2,935	1,703
New York	5,151	3,553
North Carolina	3,790	3,250
North Dakota	2,727	3,593
Ohio	4,404	5,179
Oklahoma	3,364	3,228
Oregon	3,750	2,481
Pennsylvania	5,485	5,060
Rhode Island	269	102
South Carolina	2,624	2,300
South Dakota	2,938	1,837
Tennessee	3,255	2,609
Texas	13,330	10,246
Utah	2,178	1,452
Vermont	698	568
Virginia	3,491	3,236
Washington	3,423	3,179
West Virginia	1,823	2,258
Wisconsin	4,172	3,400
Wyoming	2,950	1,862

Source: FHWA, 2004; Association of American Railroads, 2004.



Source: Federal Highway Administration, http://www.fhwa.dot.gov/hep10/nhs/

Figure 3-31. National Highway System



Source: FHWA, 2007.

Figure 3-32. Map of High Priority Corridors

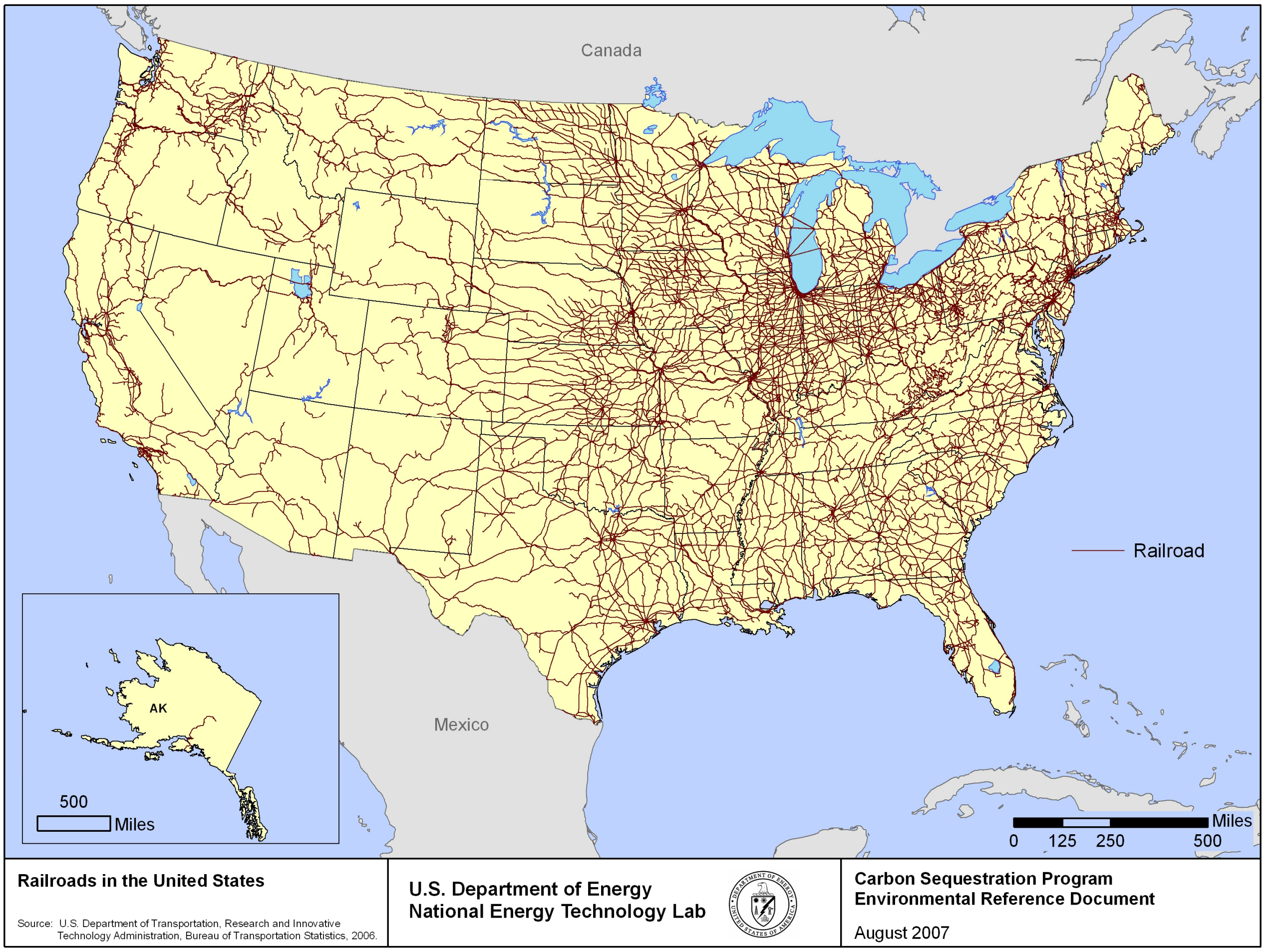


Figure 3-33. Rail Network of the United States

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